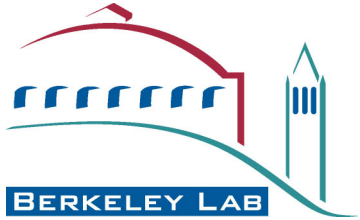
ALICE Overview

Mateusz Ploskon

On behalf of

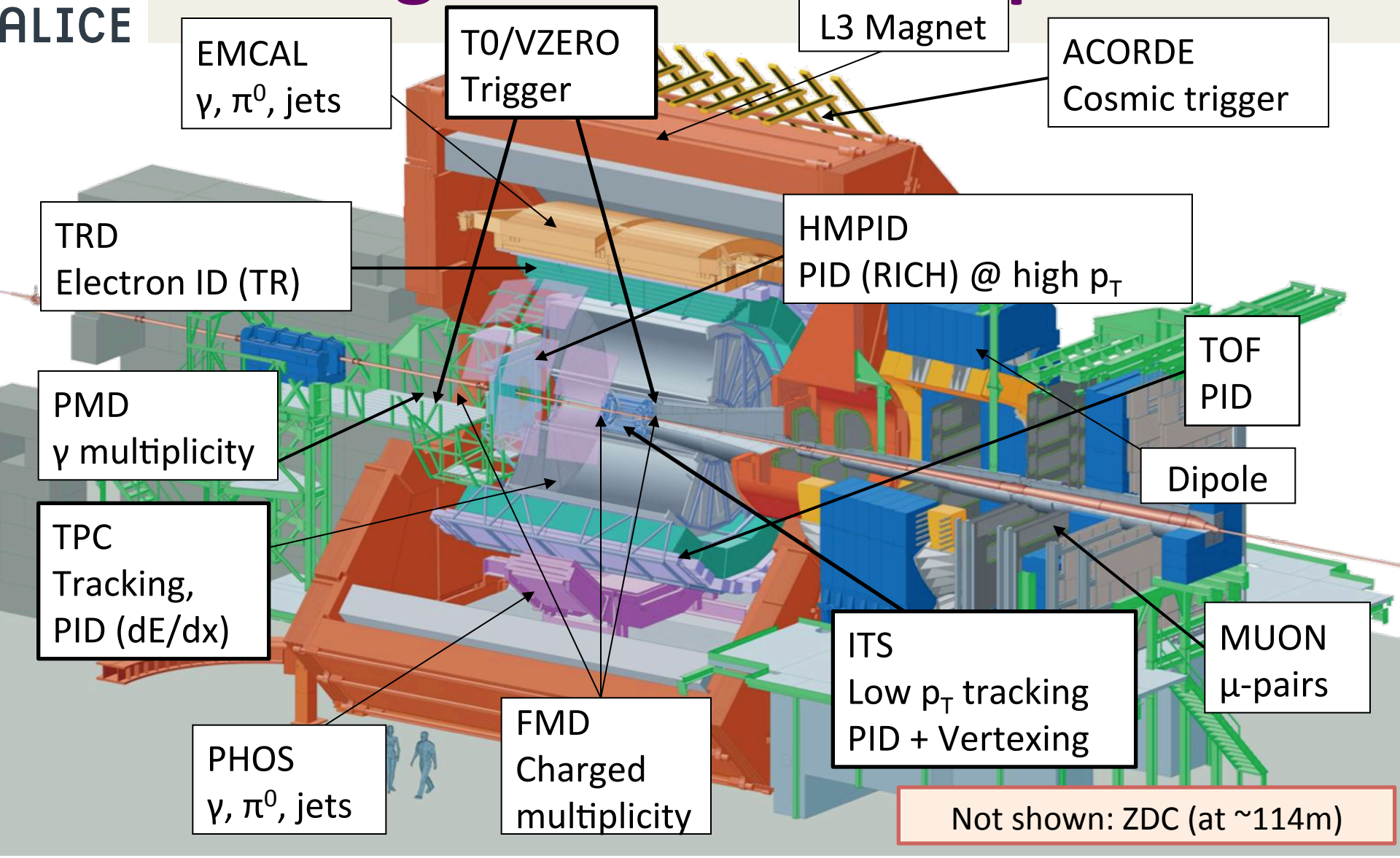
ALICE Collaboration



Broad view outline

- Heavy-ion collisions at LHC energies
  - Extract physical properties of the hot de-confined QCD matter: $T>>T_c$ at $\mu_b=0$
  - Must have: sensitivity of observables to QGP effects
- pA collisions: cold nuclear matter
  - Understanding of initial state of AA collisions
  - Must test: sensitivity of observables to QGP effects
- proton-proton collisions:
  - Vacuum reference; p-QCD jet cross-section
  - Single NN ≠ single parton-parton interaction
  - Is this the best reference for all observables?

A Large Ion Collider Experiment



ALICE at SQM

Systems:

- Proton-proton
- pPb
- PbPb

- Outline of this talk:
  - Selected subjects from soft to hard probes
  - Summary

Properties & Tools

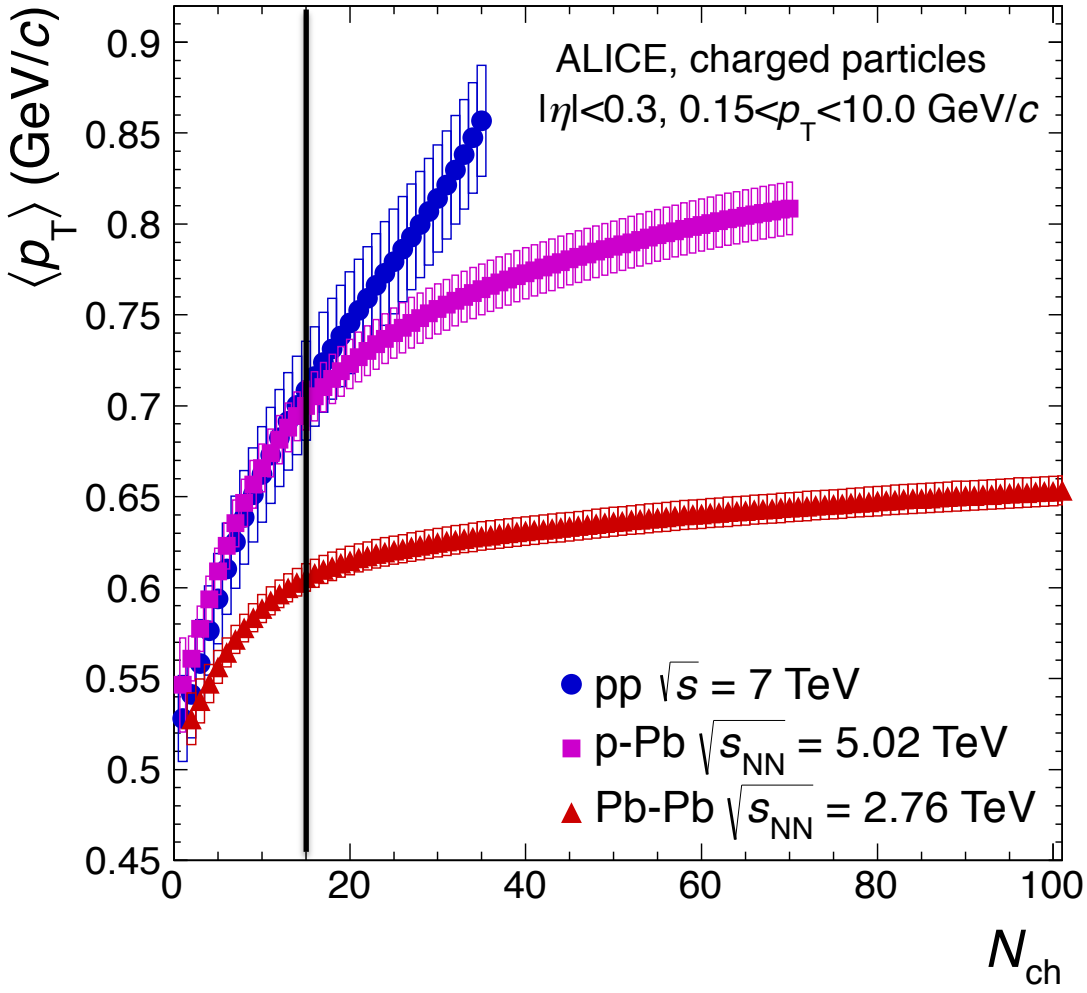
- Global event / system properties:
  - Inclusive spectra; Identified particles; mean pT; Blast-wave fits (T, Beta)
- Collective effects
  - Correlations, flow coefficients, v_2, v_3 (propagation/dissipation)
- Heavy-flavour – e-loss and thermalization
  - Production vs. multiplicity; Suppression and v2
- Quarkonia – QGP vs. Cold Nuclear Matter
  - Production vs. multiplicity; Suppression in PbPb; v2; suppression/enhancement in pA
- Jets
  - R_{AA} – inclusive production in pp and AA; jet structure; test of N_{binary} scaling in min. bias pPb

GLOBAL EVENT PROPERTIES

Global event properties: mean pT vs multiplicity

arXiv:1307.1094

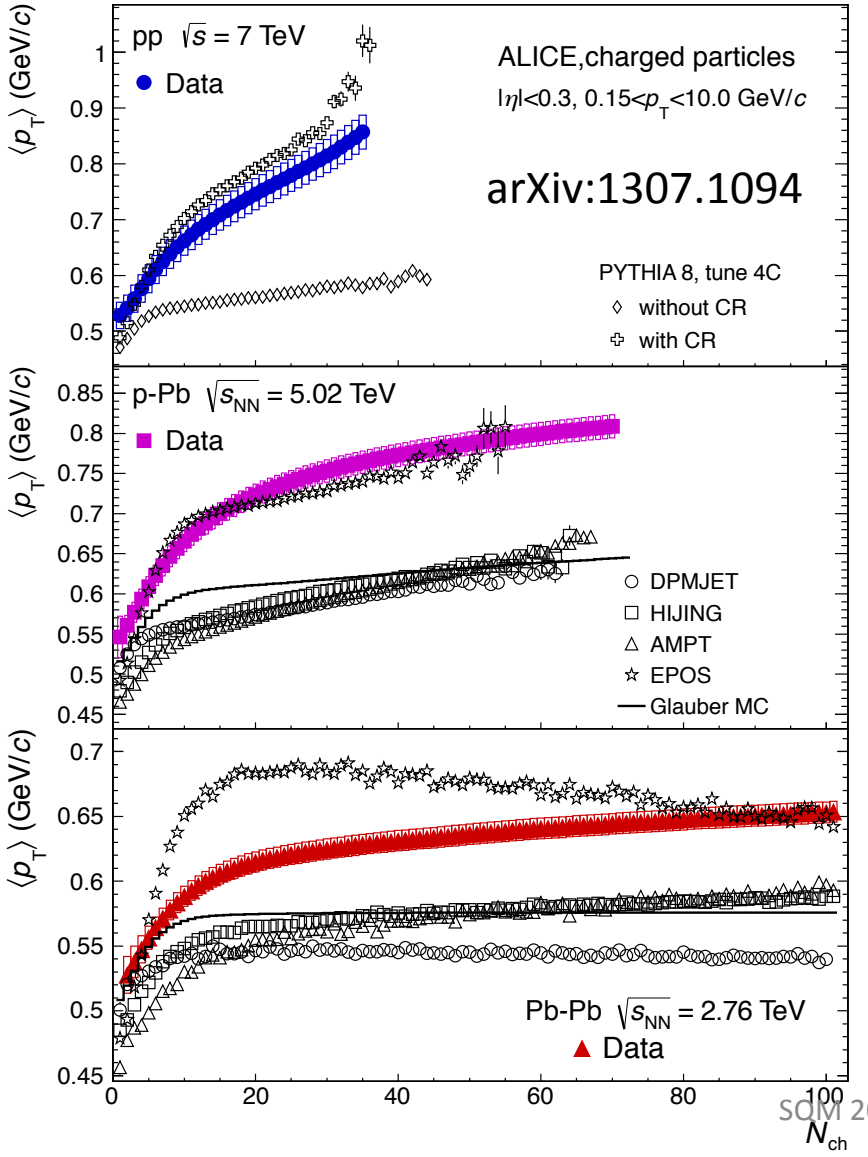
A. Morsch Thu 11:30



Proton-proton and pPb follow the same trend up to **Nch~15**; however: this is **90% of pp x-section and 50% of pPb x-section** (different biases)

pp and pPb – much stronger increase than in PbPb

Global event properties: mean pT vs multiplicity



- Proton-proton: PYTHIA - strong increase with Nch attributed to **Color Reconnections** between hadronizing strings - a collective final state effect

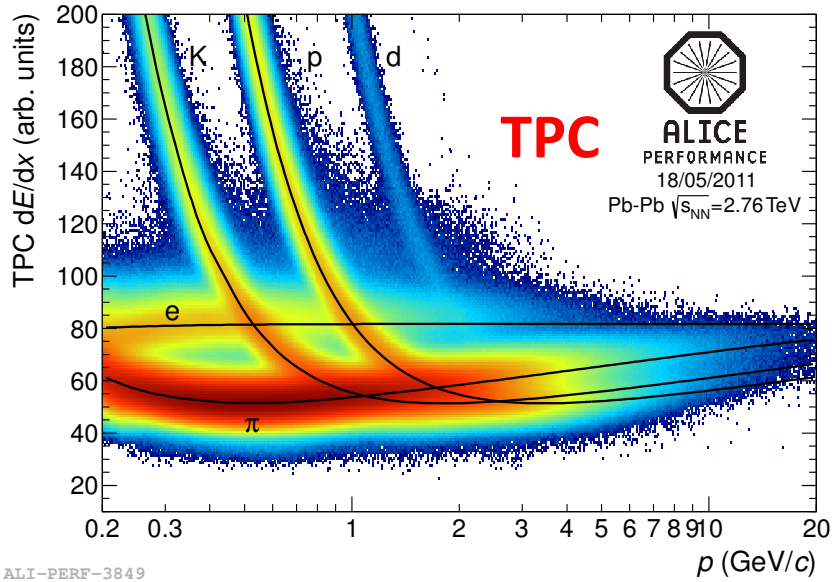
- pPb:
  - Glauber MC (incoherent p-N's) using measured <pT> in pp does not work
  - Coherent effects via strings from different p-N?
  - EPOS includes collective effects.

- Pb-Pb: DPMJet gets trend right. EPOS has different shape for very peripheral collisions.

A. Morsch Thu 11:30

IDENTIFIED PARTICLE PRODUCTION

ALICE: Particle identification



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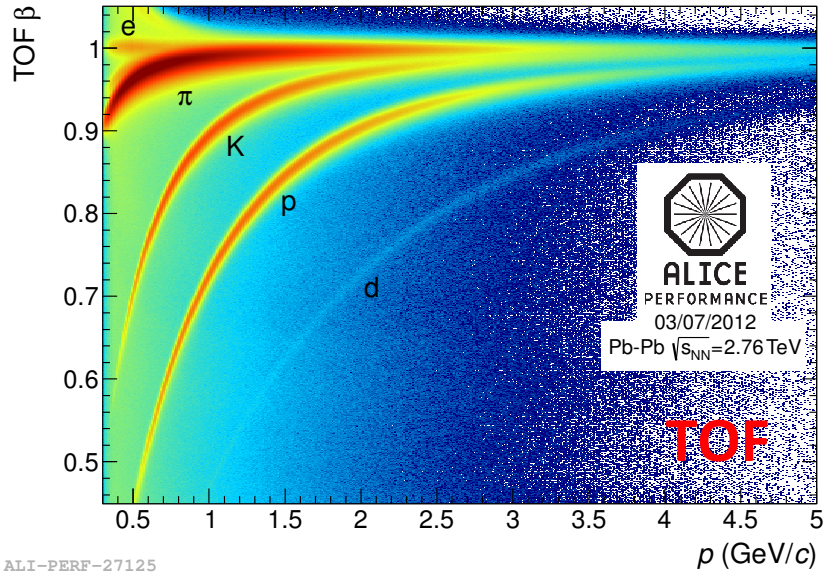

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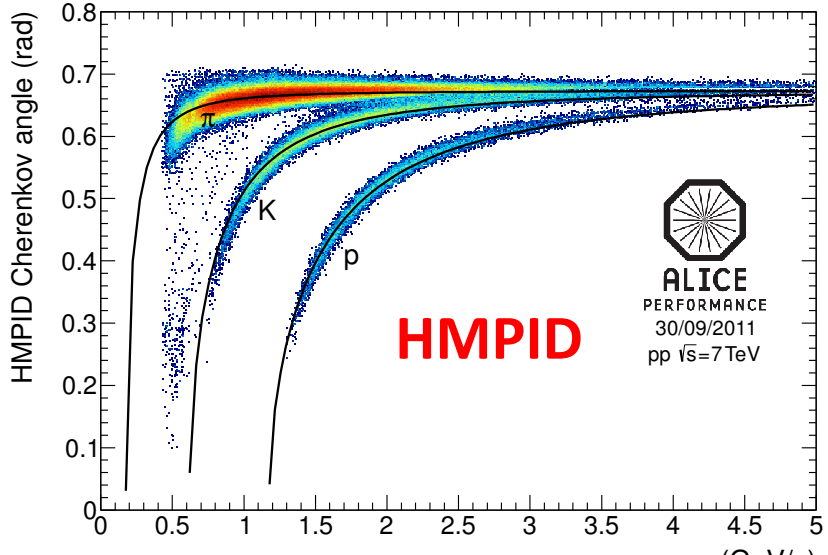

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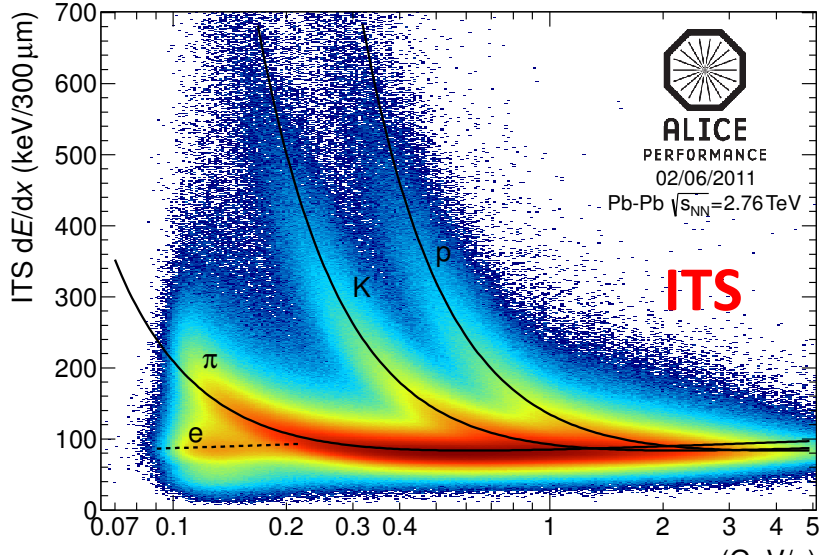

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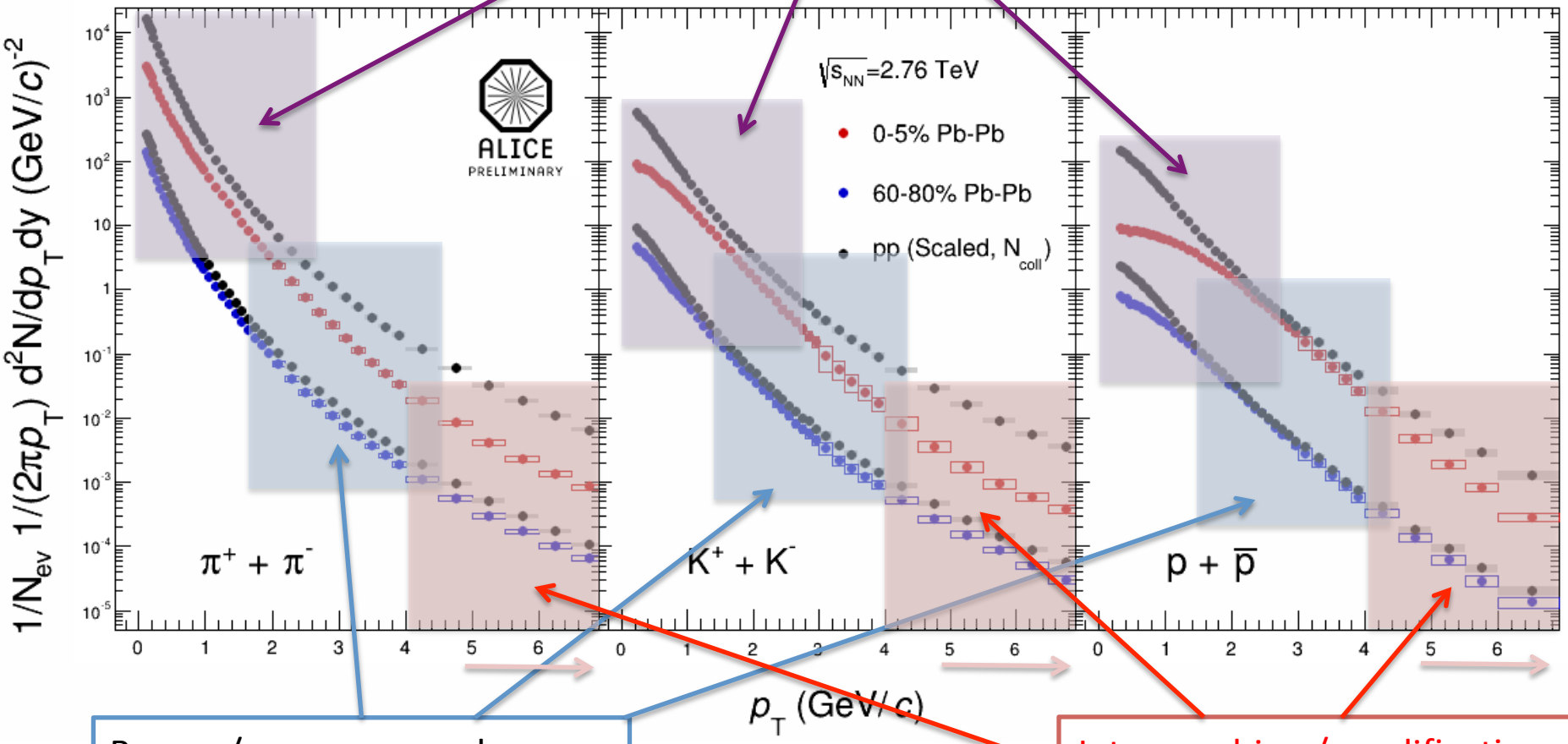
Pion/Kaon/Proton in pp and Pb-Pb

Radial flow (mesons – protons – mass dependence)

M. Chojnacki Tue 14:40

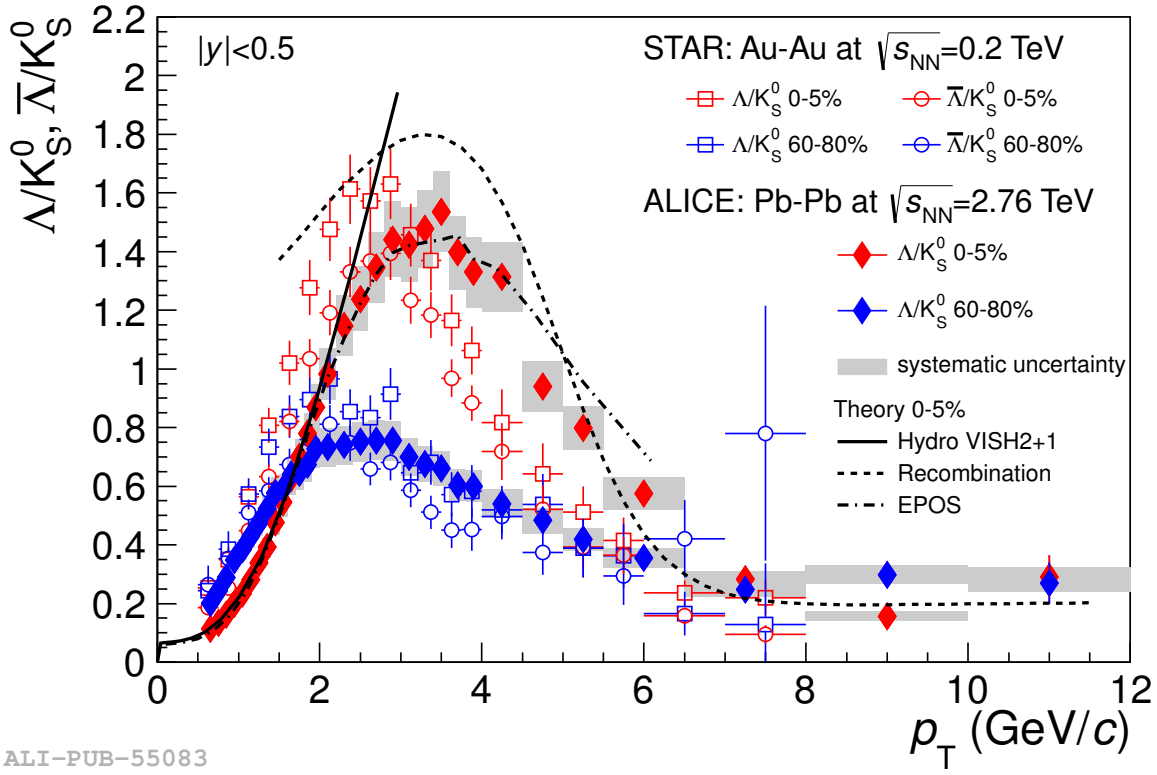


Baryon/meson anomaly
- Radial flow / recombination?

Jet quenching / modifications of jet fragmentation?

L/K0s

L. Hanratty Thu 17:10



Submitted
arXiv 0764109

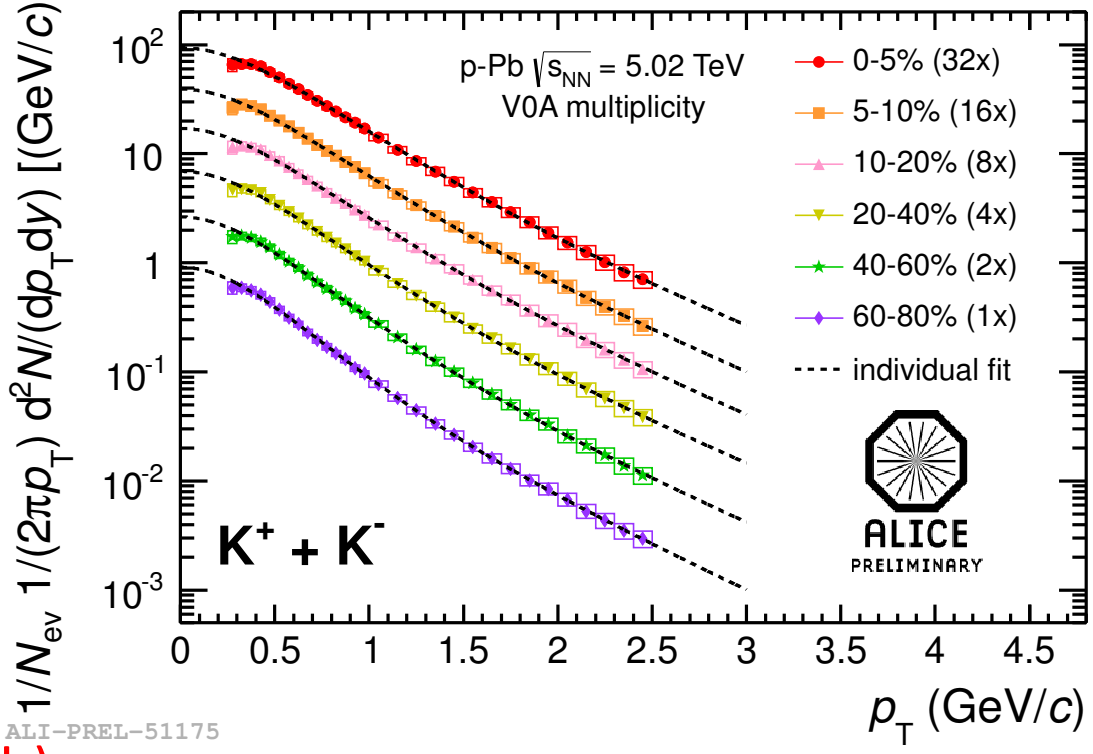
- Integrated ratio independent of centrality ($\Lambda/K^0_s \sim 0.25$)
- Intermediate pT: Λ/K^0_s ratio enhanced in central Pb-Pb
  - consistent with radial flow
- High-p_T: ratio consistent with vacuum-like fragmentation.

Identified particles in p-Pb

J. Anielski Fri 15:40

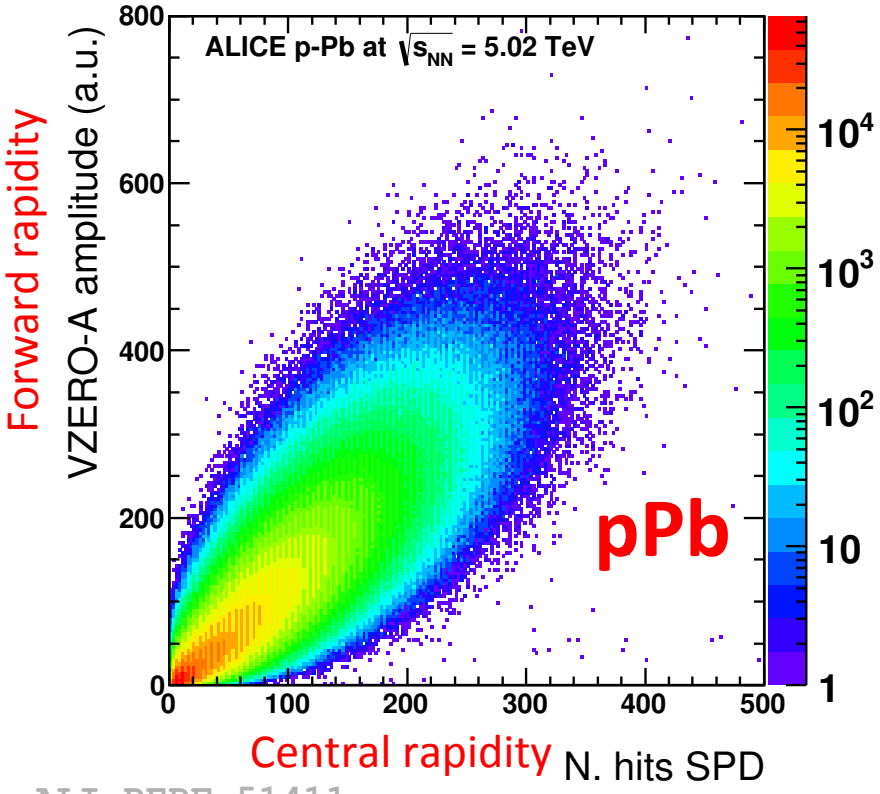
- Yields of pions, charged kaons, protons (TPC+TOF) and K0s, Lambda's (inv. mass)
- Binned in percentiles of multiplicity of VZERO-A detector
- Fitted with blast-wave
- Not shown: studied <pT> (mass ordering present)
- and ratios of particles (dependence on dN/dh similar in pp, pPb and PbPb)

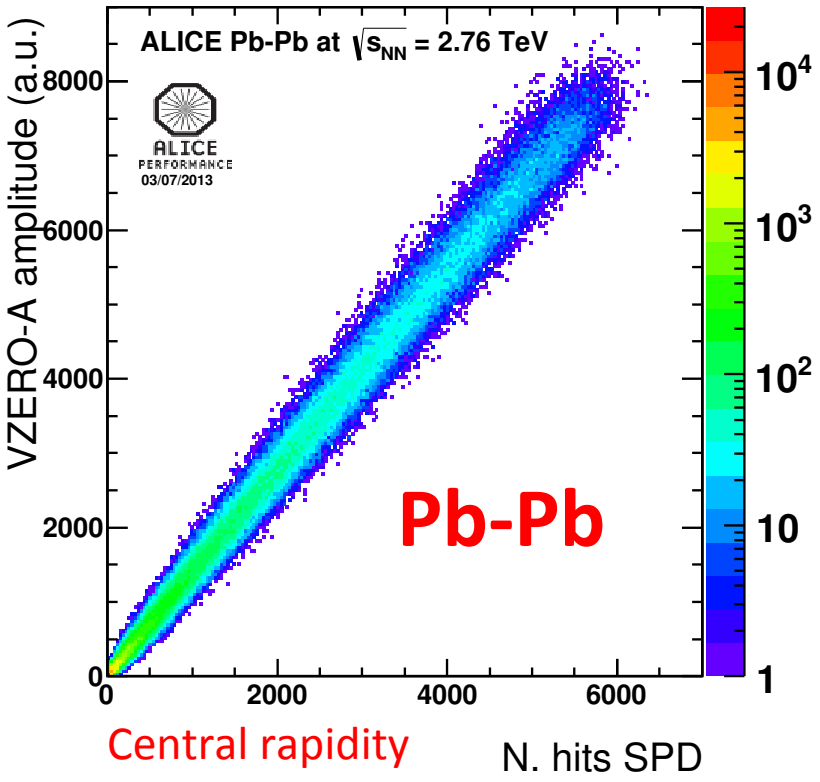
Submitted / arXiv



Intermezzo: p-Pb multiplicity

A. Morsch Thu 11:30





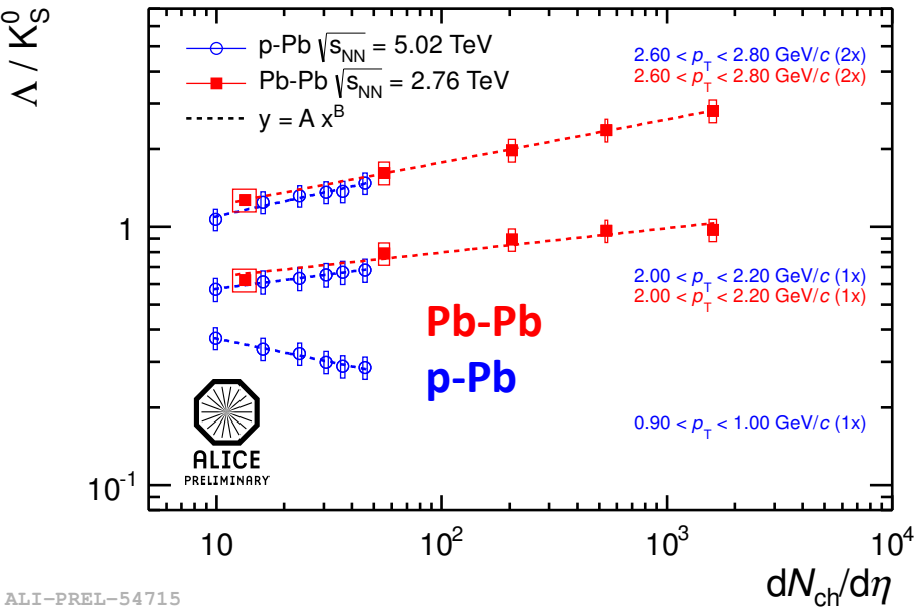
Much broader correlation between different multiplictiy (event class) estimators

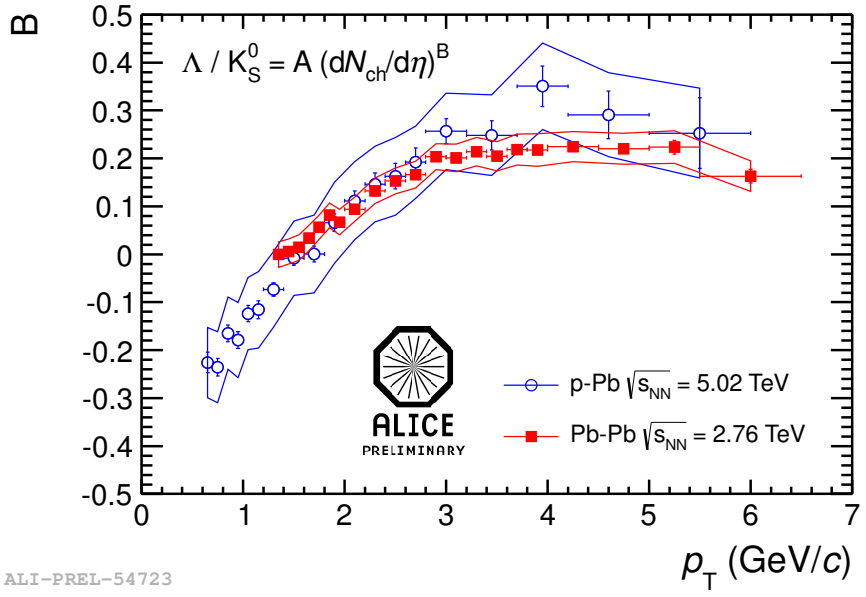
⇒ expect different sensitivity (bias) to event geometry (Glauber! – Ncoll scaling)

Identified particles in p-Pb

J. Anielski Fri 15:40

Lambda/Kaon ratio vs. charged particle multiplicity density $R = A(\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta)^{\mathrm{B}}$



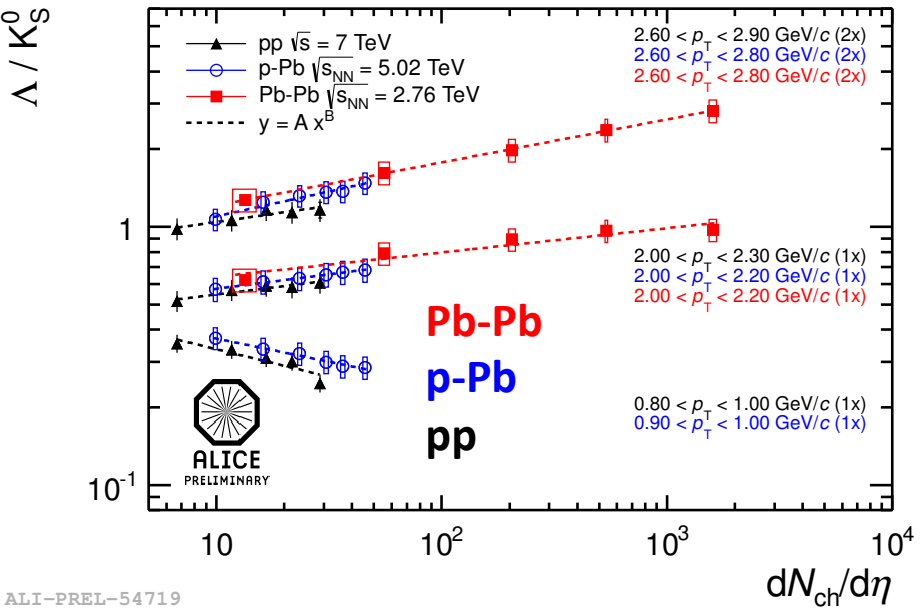


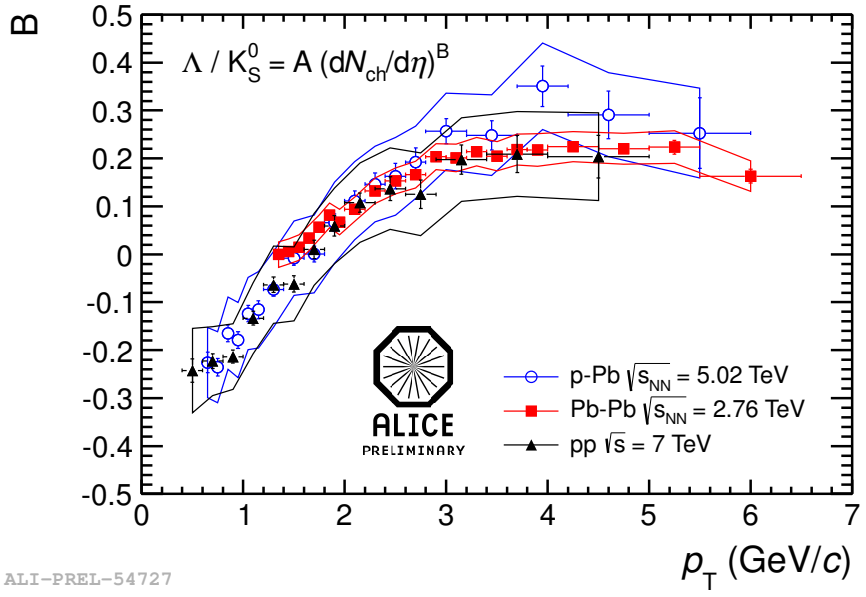
- Baryon to meson ratio:
  - **similar trend of p/pion ratio in p-Pb as in Pb-Pb per dN$_{ch}$/dη**
  - follows a **power-law with a same exponent B(p_T)** in two systems (although in p-Pb much smaller than in Pb-Pb case) - similar case for proton/pion ratio

Identified particles in p-Pb

J. Anielski Fri 15:40

Lambda/Kaon ratio vs. charged particle multiplicity density $R = A(\mathrm{d}N_{\mathrm{ch}}/\mathrm{d}\eta)^{\mathrm{B}}$

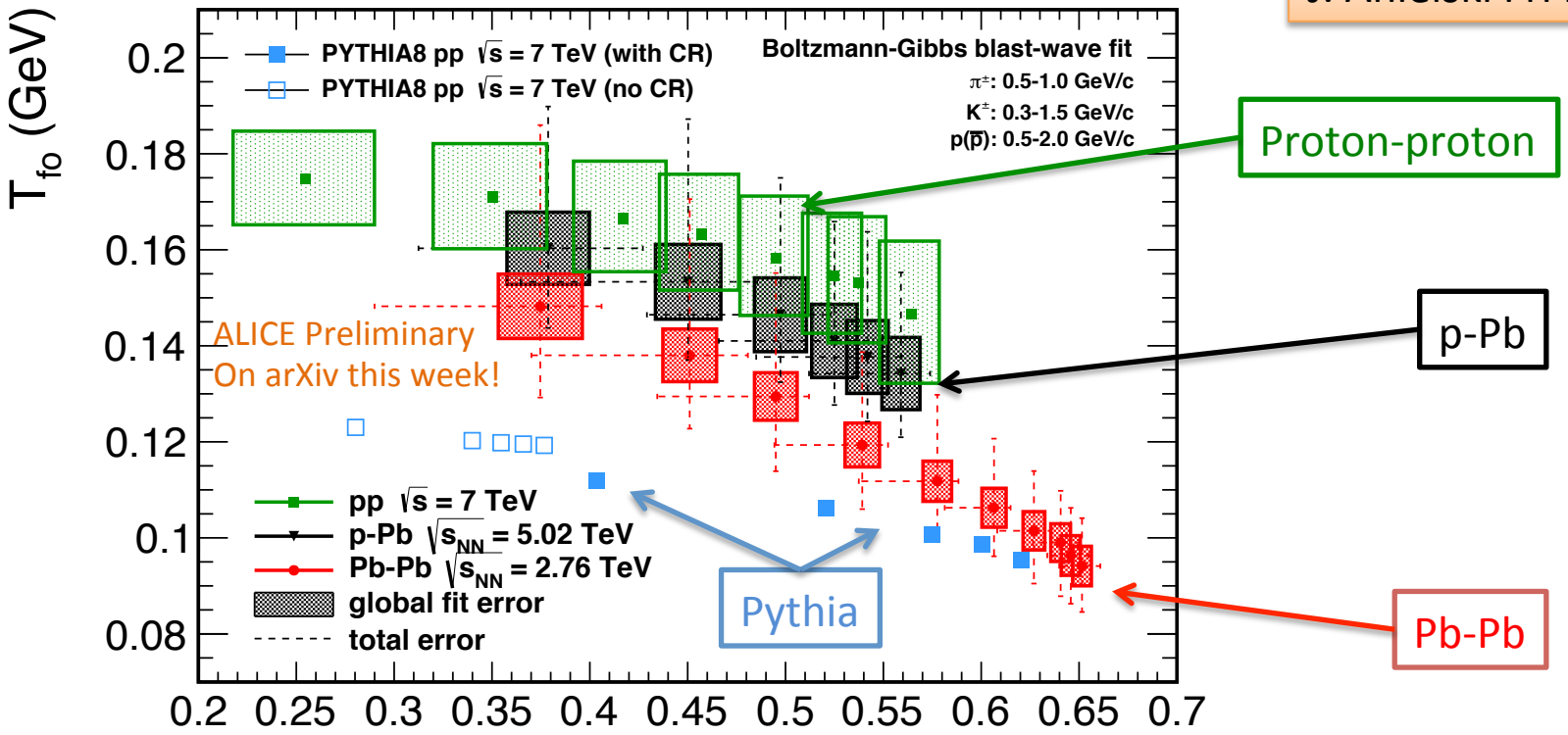




- Baryon to meson ratio:
  - **similar trend of p/pion ratio in p-Pb as in Pb-Pb per $dN_{ch}/d\eta$**
  - follows a **power-law with a same exponent B(p_T)** in two systems (although in p-Pb much smaller than in Pb-Pb case) - similar case for proton/pion ratio
  - **Same trend in proton-proton collisions**

Blast-wave in pp, pPb and Pb-Pb

J. Anielski Fri 15:40

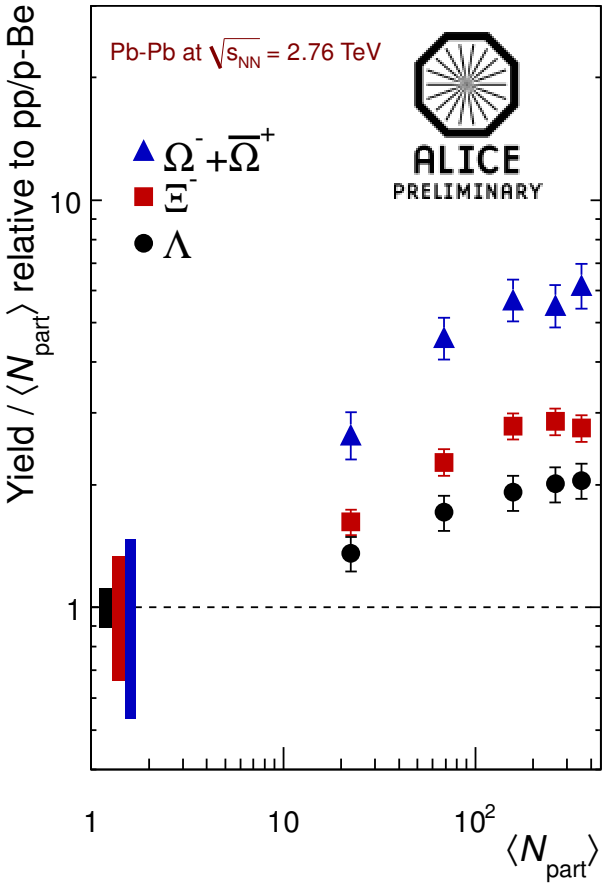


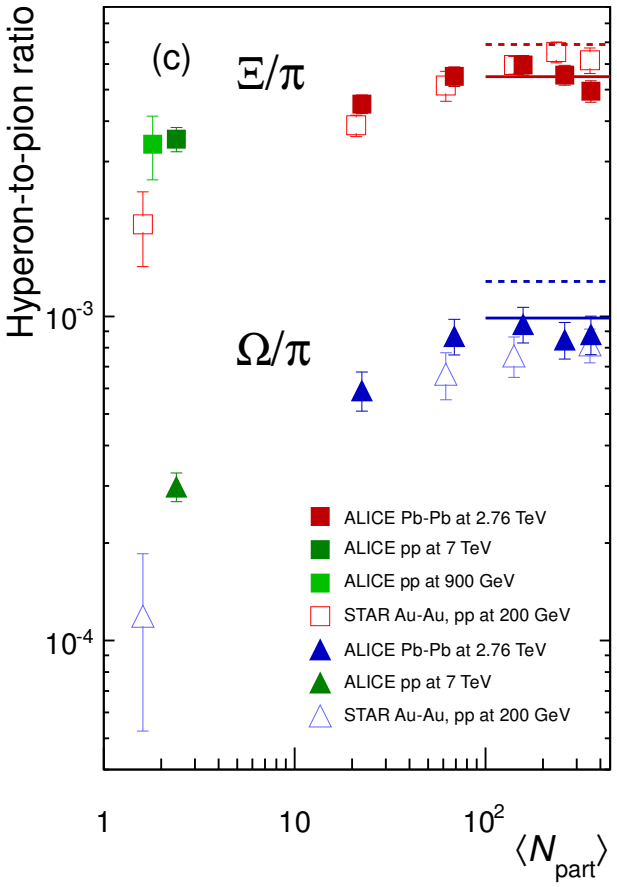
- **Blast-wave fits: similar T vs Beta trend in p-Pb and Pb-Pb;**
  - however, also in pp collisions
- **Fits (spectra) sensitive not only to a collective behavior (radial flow) but also to other sources of correlations? -> pp, p-Pb cases**
- **Pythia – vacuum case and no radial flow – Color Reconnections – source of correlations in the final state – impact on the spectra shape (fit sensitivity)**

Multi-strange baryons

Enhancement pattern (strangeness content) preserved at LHC – also the expected sqrt(s_{NN}) energy dependence observed

L. Barnby Mon 15:50
D. Colella Thu 16:50





Hyperon to pion ratio – as expected from thermal model (Andronic et. al)

LHC: ALICE – solid points
RHIC: STAR – hollow points

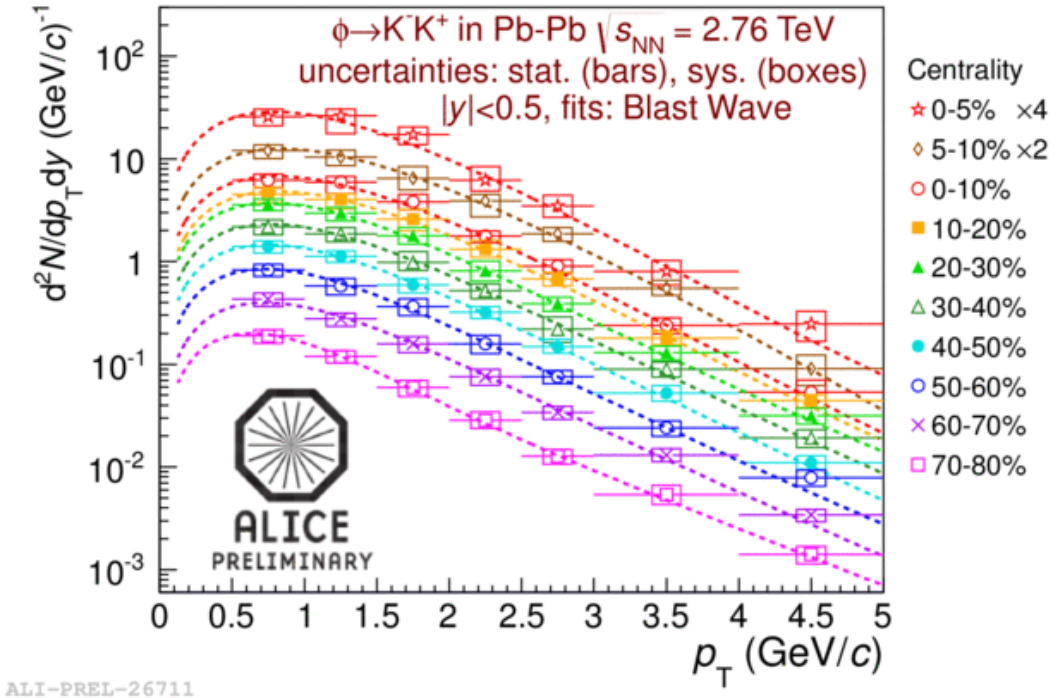
ALI-DER-57382

ALI-PUB-57317

Hadronic resonances in Pb-Pb

A. Knospe Thu 17:10

- Production/abundance sensitive to temperature and lifetime of fireball
  - time between chemical to kinetic freeze-out
- Mass and width – sensitivity to chiral symmetry restoration
  - No modifications seen in the data



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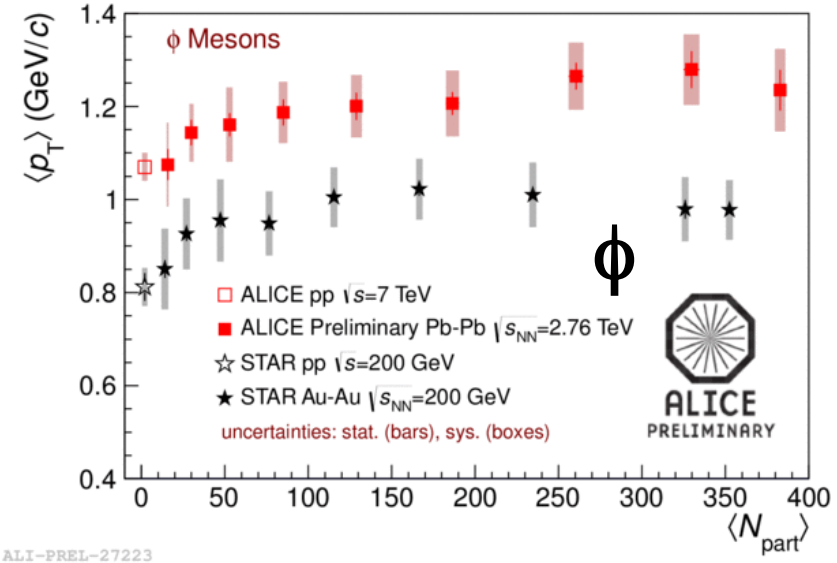
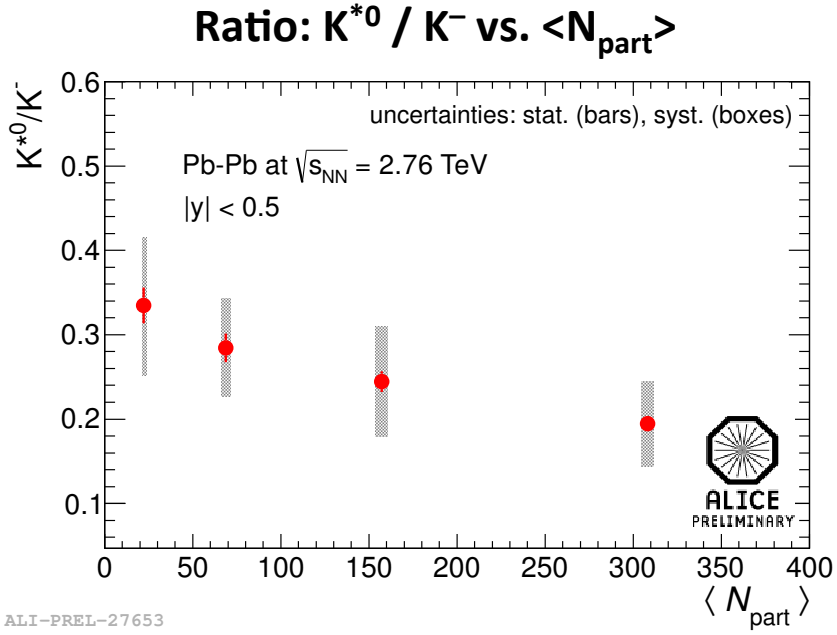


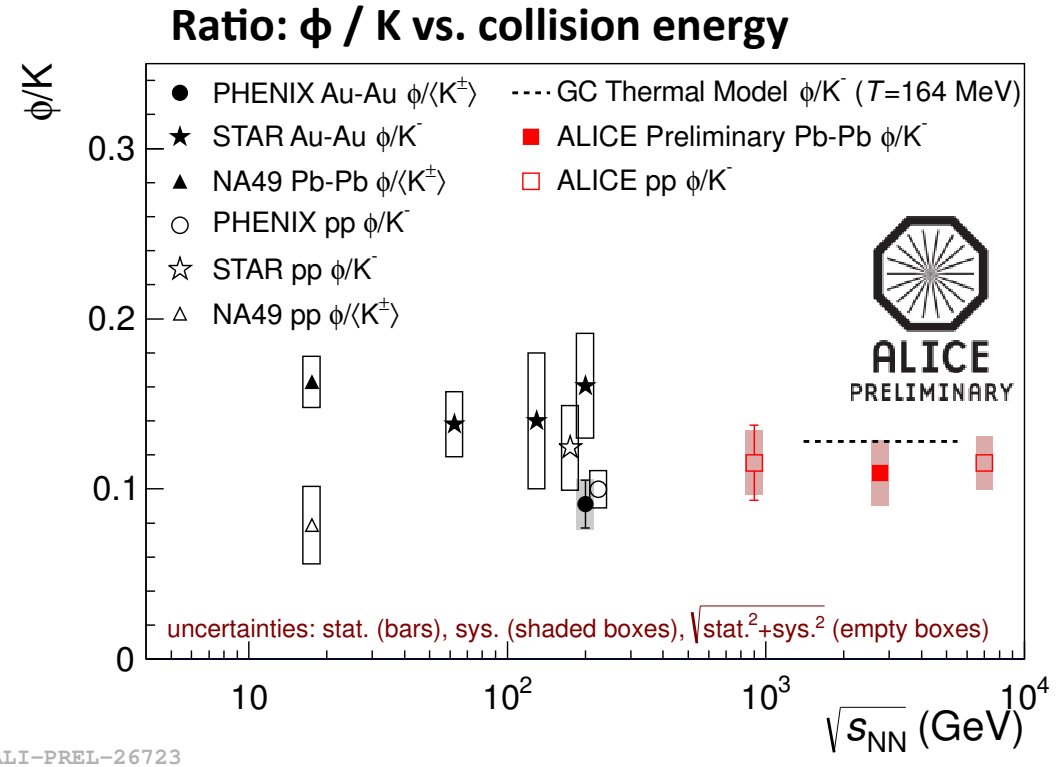
ALI-PREL-27223

<pT> at LHC larger than at RHIC
– consistent with stronger radial flow

Hadronic resonances in Pb-Pb

A. Knospe Thu 17:10





- K^{*0}/K^{-} decreases for central collisions
  - signature for re-scattering in central collisions
- ϕ/K independent of energy and system from RHIC to LHC
  - Pb–Pb: consistent with Grand Canonical thermal model (Andronic *et al.*)

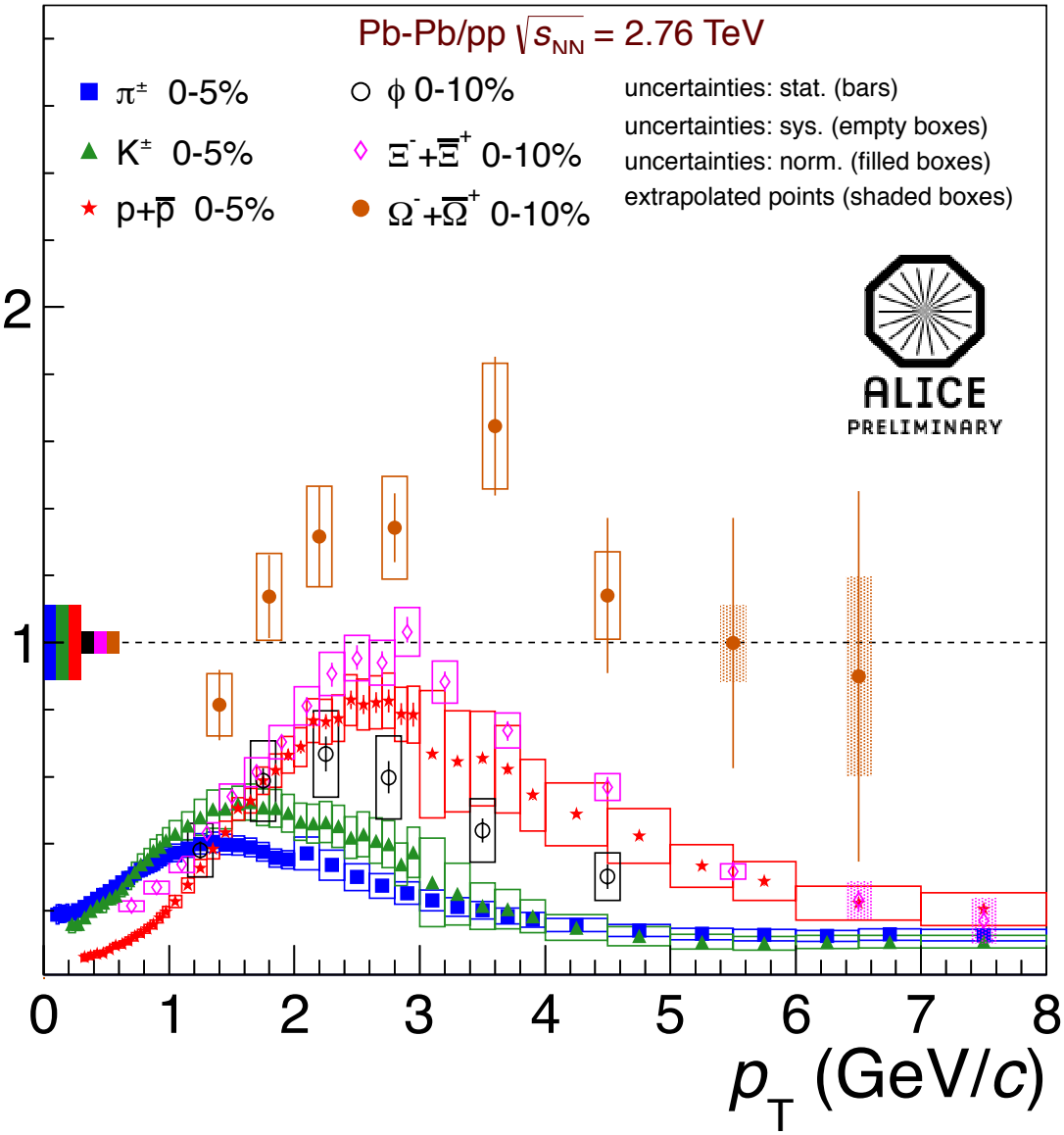
R_{AA} of identified particles

ϕ in 0-10%:

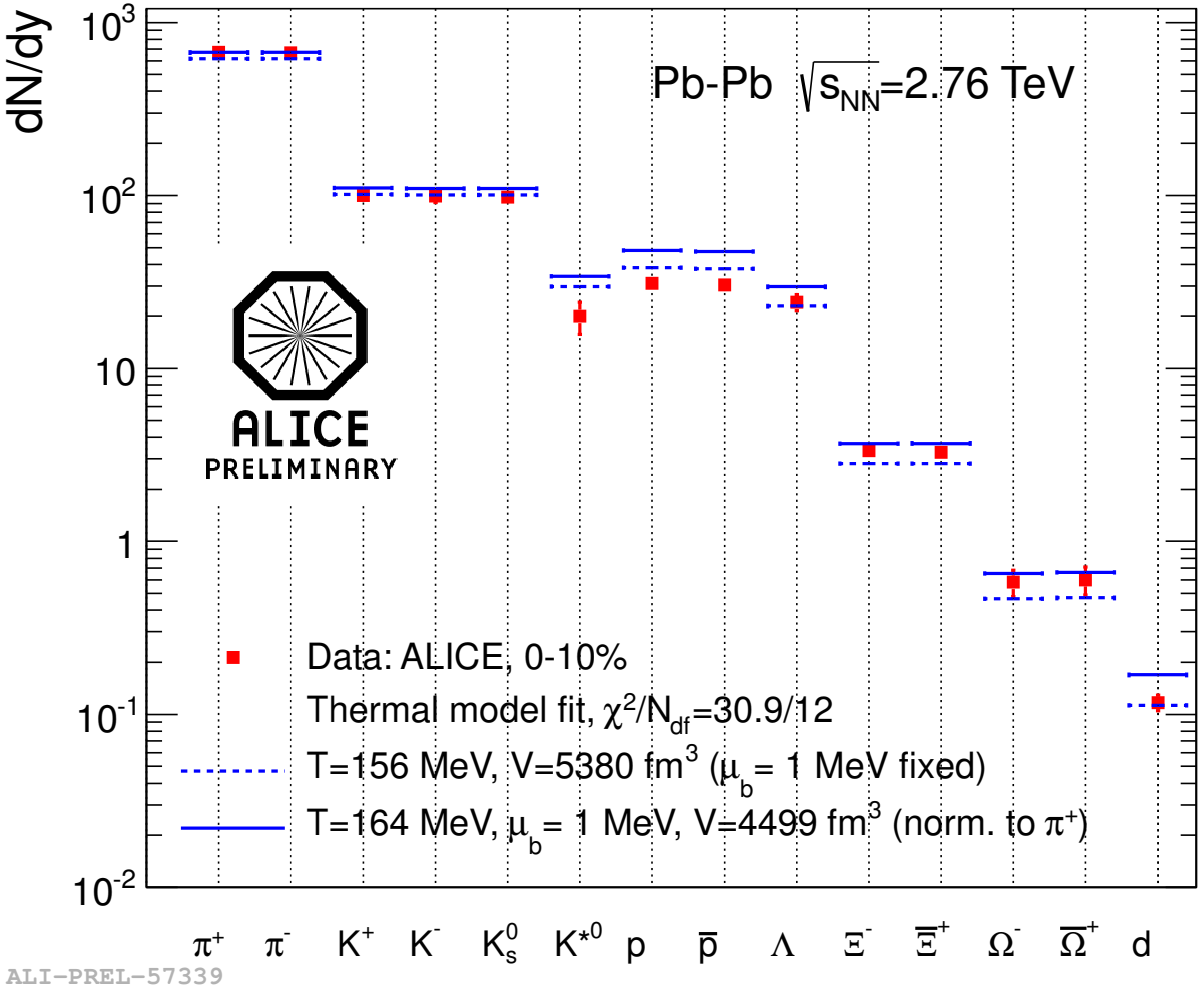
- **Similar to proton below 2 GeV/c**
- **Between pion and proton above 2 GeV/c**

Ξ R_{AA} compatible with protons

Ω – large R_{AA} consistent with enhancement in HI collisions; however, largely due to the suppression in pp



Thermal fits



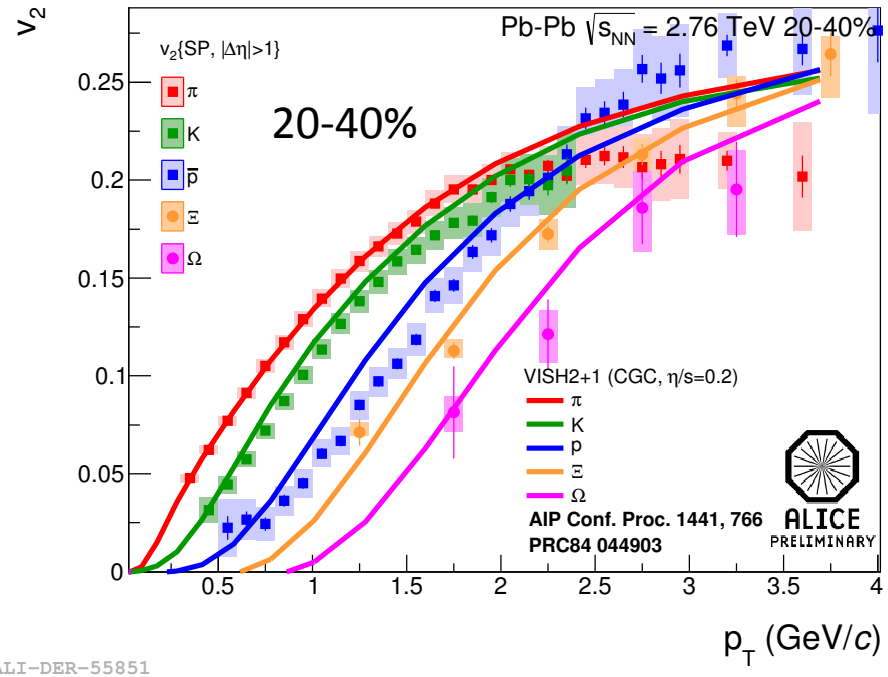
Remaining data-fit tension – possible contributions:

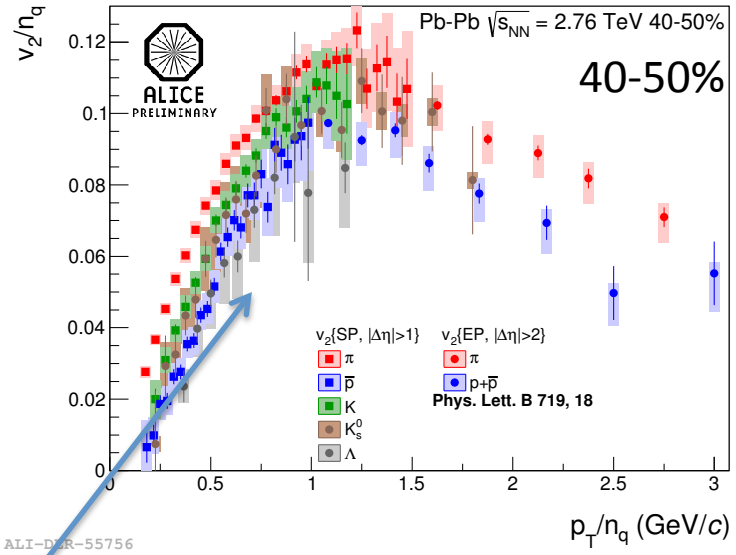
- late stage baryon-antibaryon annihilation (specifically p-pbar)
- sequential freeze-out of different different quark flavours
- non-equiibrium freezeout conditions
- Unknown/unmeasured baryon resonance spectrum proton

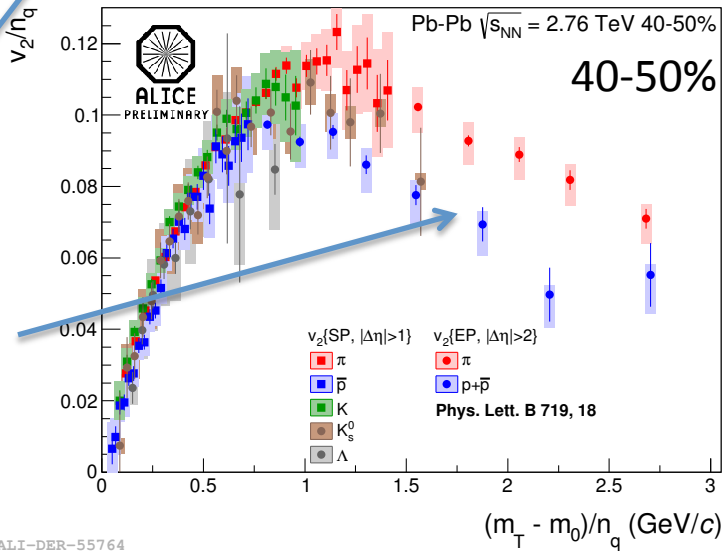
V2 of identified particles

Y. Zhou Tue 14:00

- Mass ordering for multi-strange baryons
  - Described by hydrodynamical model(s)







- v_2/n_q scaling at the LHC less obvious (within ~20%)
- For $(m_T-m_0)/n_q$>1 GeV/c v_2 of p is lower than of π

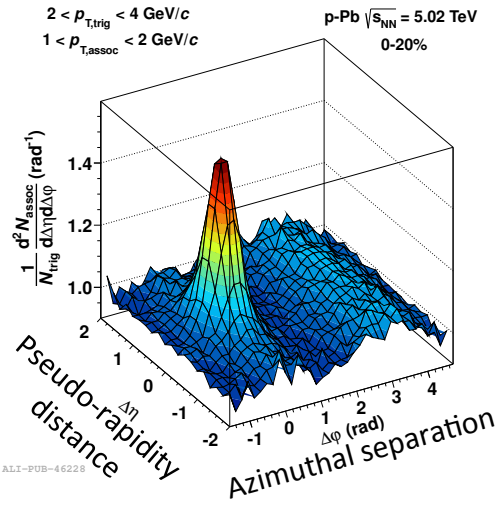
Not shown: v3(pT) – mass ordering reproduced by hydro; pion-proton intersect – expected from coalescence

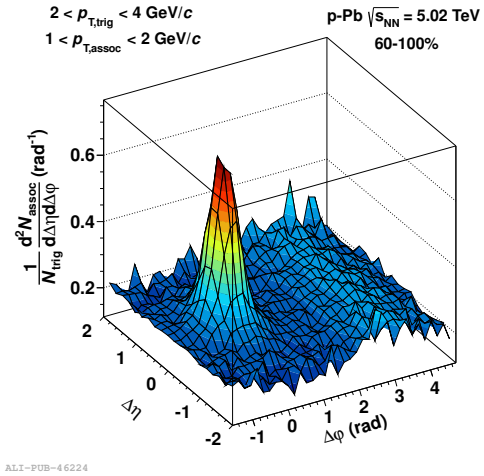
Two-particle correlations in p-Pb

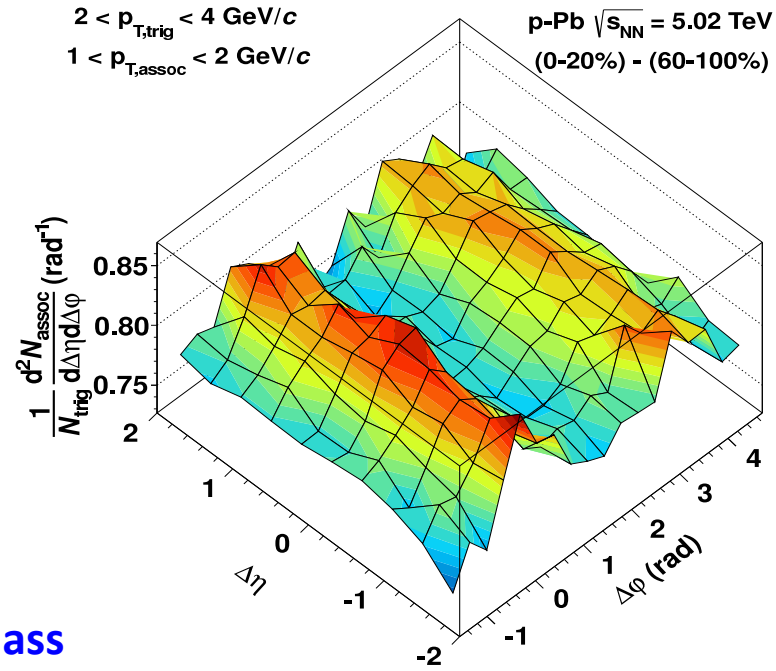
ALICE: arXiv:1212.2001

L. Milano Fri 15:20

The method: from the high-multiplicity yield subtract the jet yield in low-multiplicity events (no ridge)







High multiplicity event class

$\langle dN_{ch}/d\eta \rangle \sim 35$

Low multiplicity event class

$\langle dN_{ch}/d\eta \rangle \sim 7$

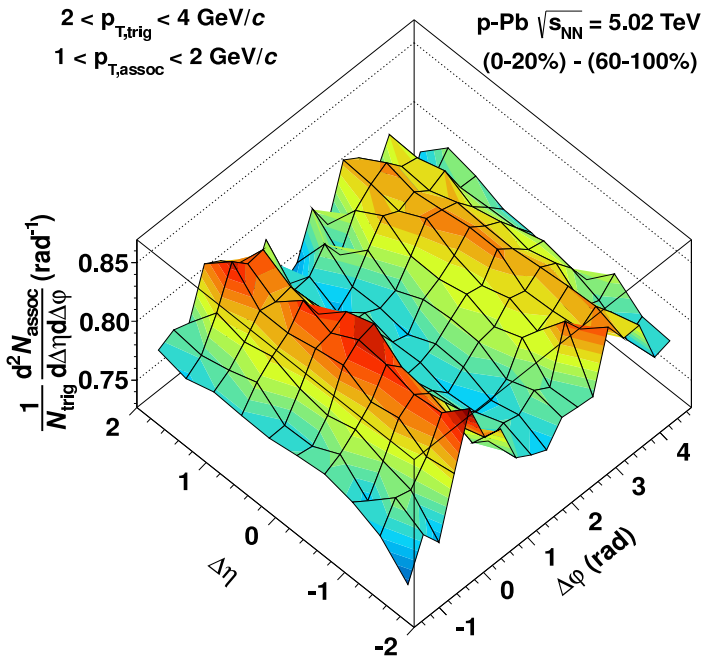
Remaining correlation: two twin long range structures

Analysis in multiplicity classes defined by the total charge in VZERO detector (away from the central region)

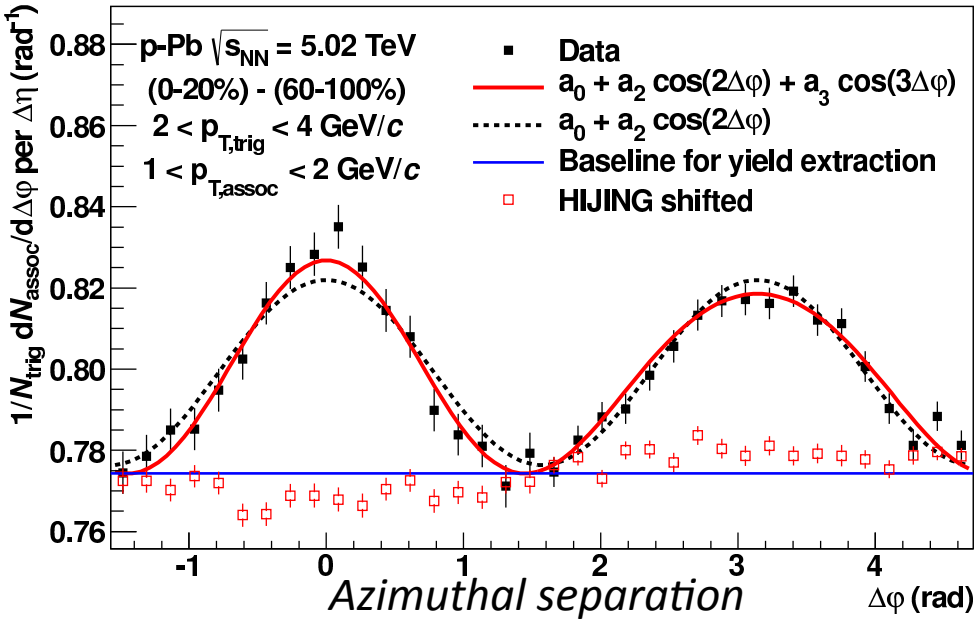
Twin ridge structure in p-Pb

ALICE: arXiv:1212.2001

L. Milano Fri 15:20



Remaining correlation described by finite amplitudes of Fourier terms



Further investigations reveal:

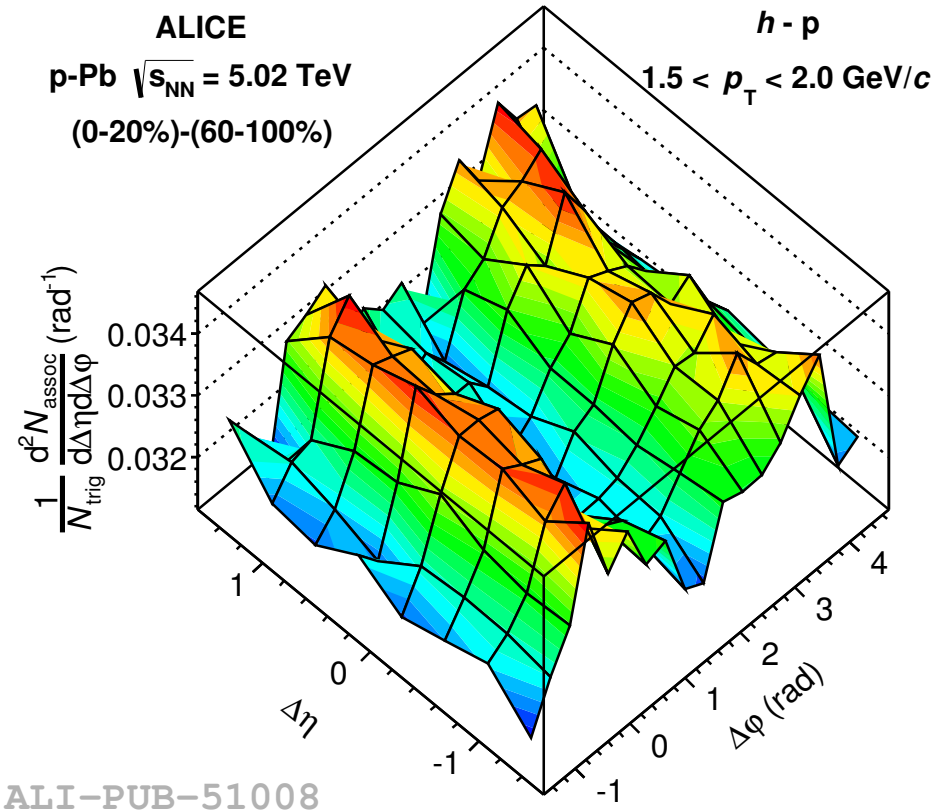
- the full modulation is (1) di-jets and (2) the double-ridge structure – nothing more
- Same yield near and away side for all classes of p_T and multiplicity suggest a common underlying process

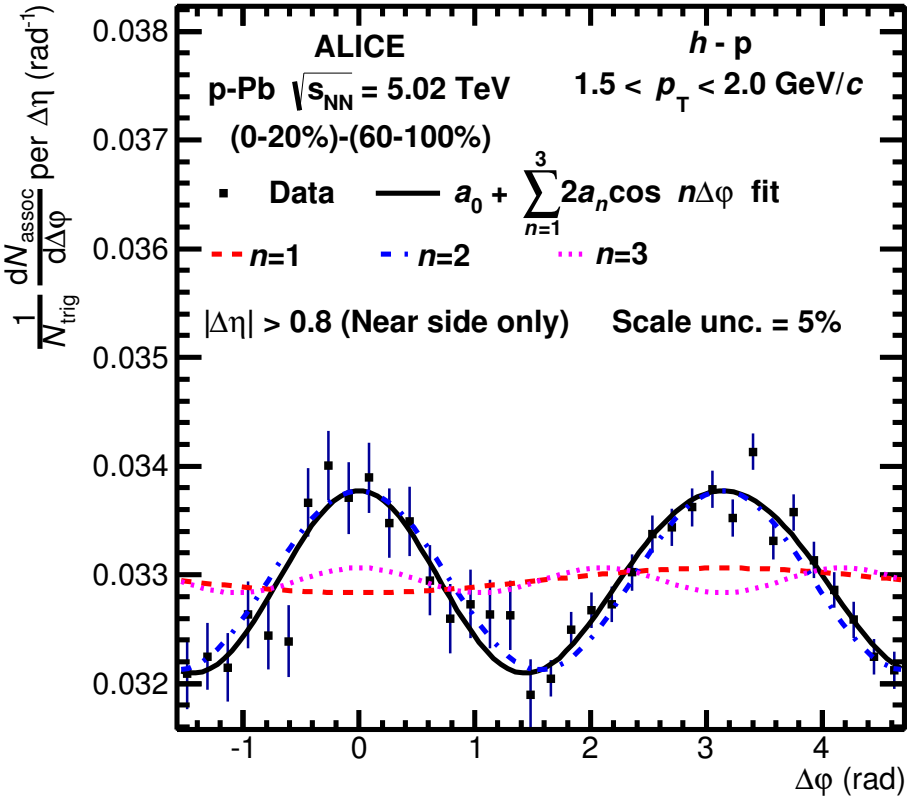
Similar observations in Pb-Pb are ascribed to collective effects!

Number of explanations put forward raging from hydrodynamic flow to CGC formalisms

Twin ridge structure in p-Pb with identified particles

Shown here: hadron-proton correlation (high-low mult. percentile subtracted)



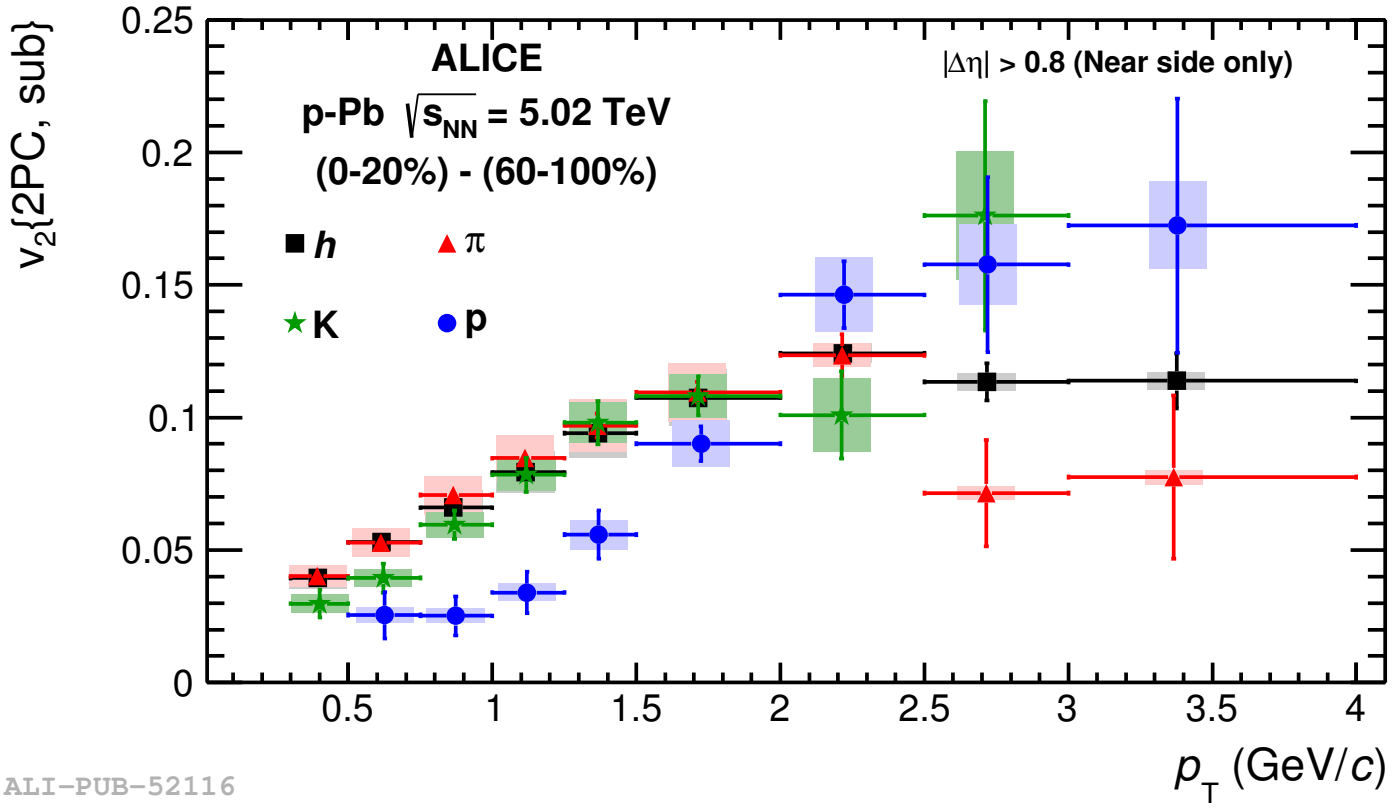


L. Milano Fri 15:20

Jet peak excluded: Δη < 0.8

v_2 coefficient in p-Pb

L. Milano Fri 15:20



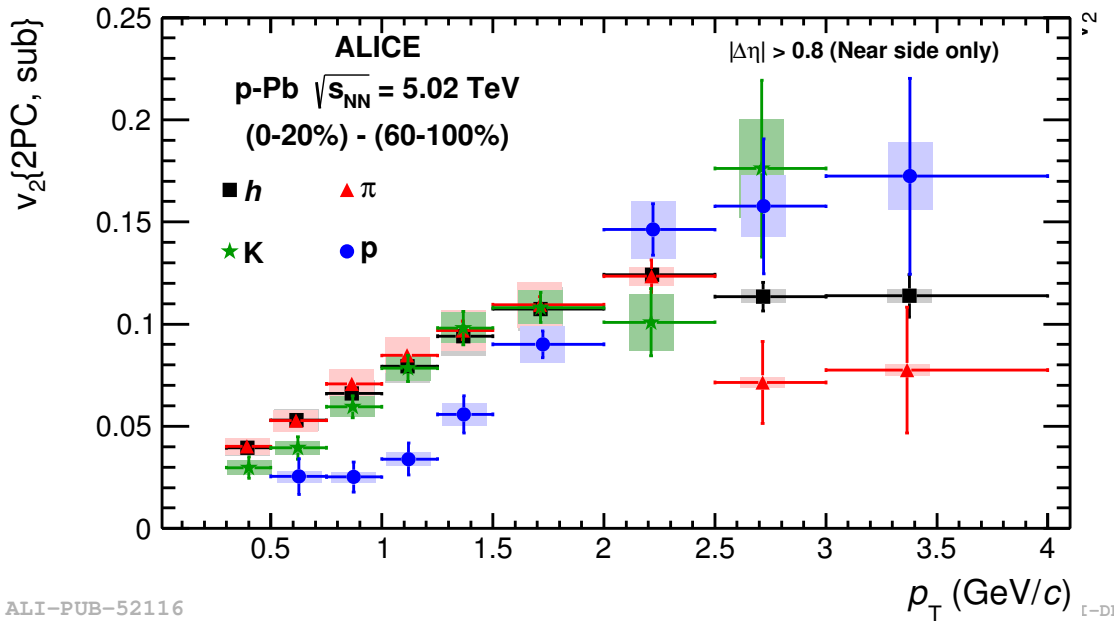
Mesons (pions and kaons) following the same trend (<2.5 GeV/c)

Intersection with protons ~2GeV

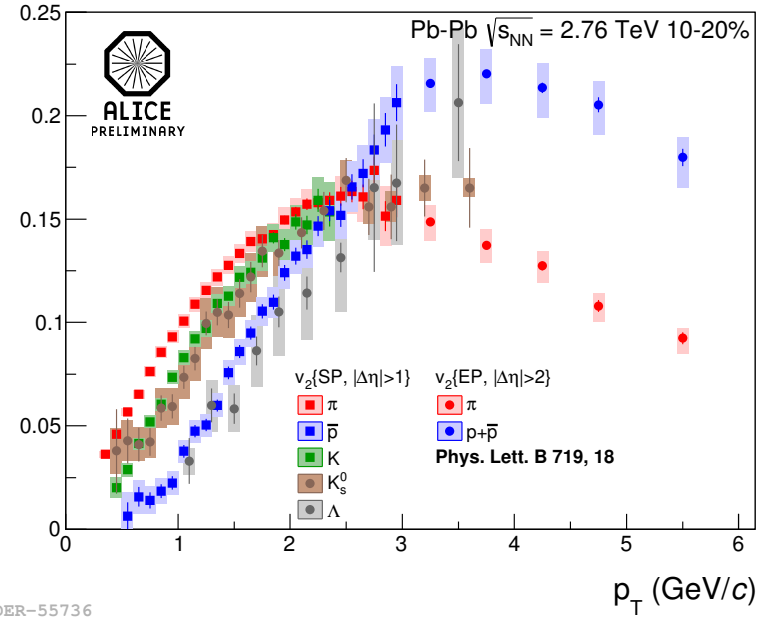
Comparison of v_2 in Pb-Pb and p-Pb

L. Milano Fri 15:20

High-multiplicity p-Pb collisions



10-20% Pb-Pb

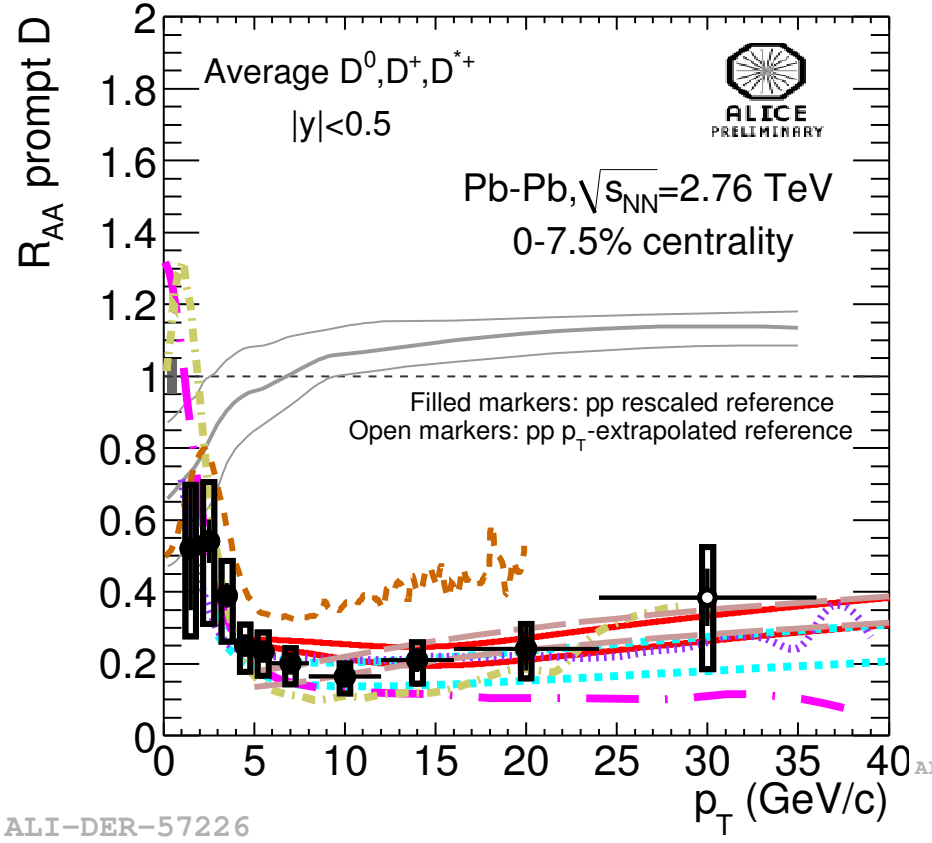


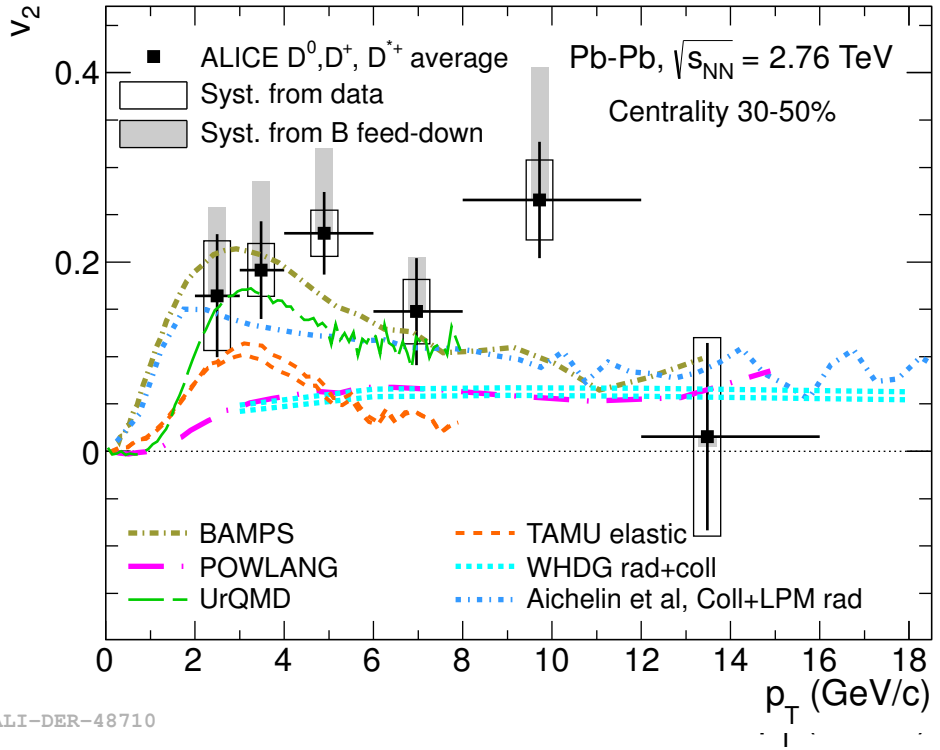
Similar features in p-Pb and Pb-Pb: mass ordering at low-pT
- in Pb-Pb ascribbed to hydrodynamics

HARD PROBES

Open charm: Challenge for theory – simultaneous description of R_{AA} and v_2

E. Bruna Thu 15:20

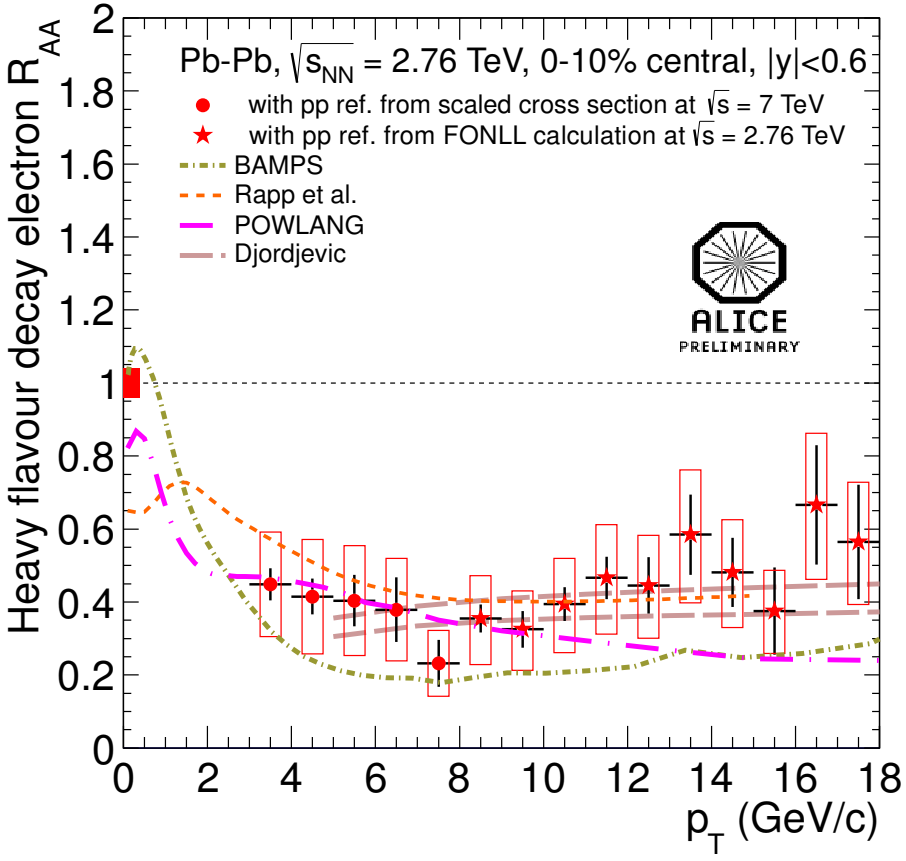


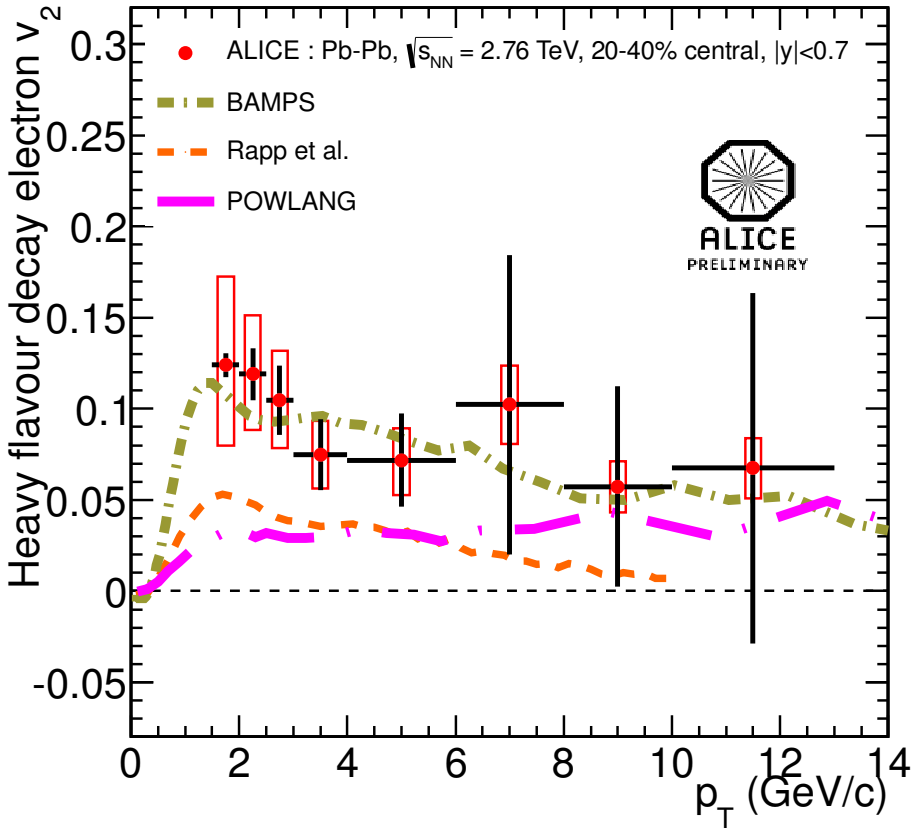


- RAA of D – similar suppression as light flavor (potential difference at pT < 8 GeV/c)
- **Non-zero D v_2 – interactions of the c-quark with thermal bulk –thermalization (?) of charm**
- **The simultaneous description of D meson R_{AA} and v_2 is a challenge to theoretical models**

D v_2 arXiv: 1305.2707

Challenge for theory – consistent description of HFE – R_{AA} and v_2





ALI-DER-57138

Heavy-flavor strongly suppressed; HFE $v_2 > 0$;

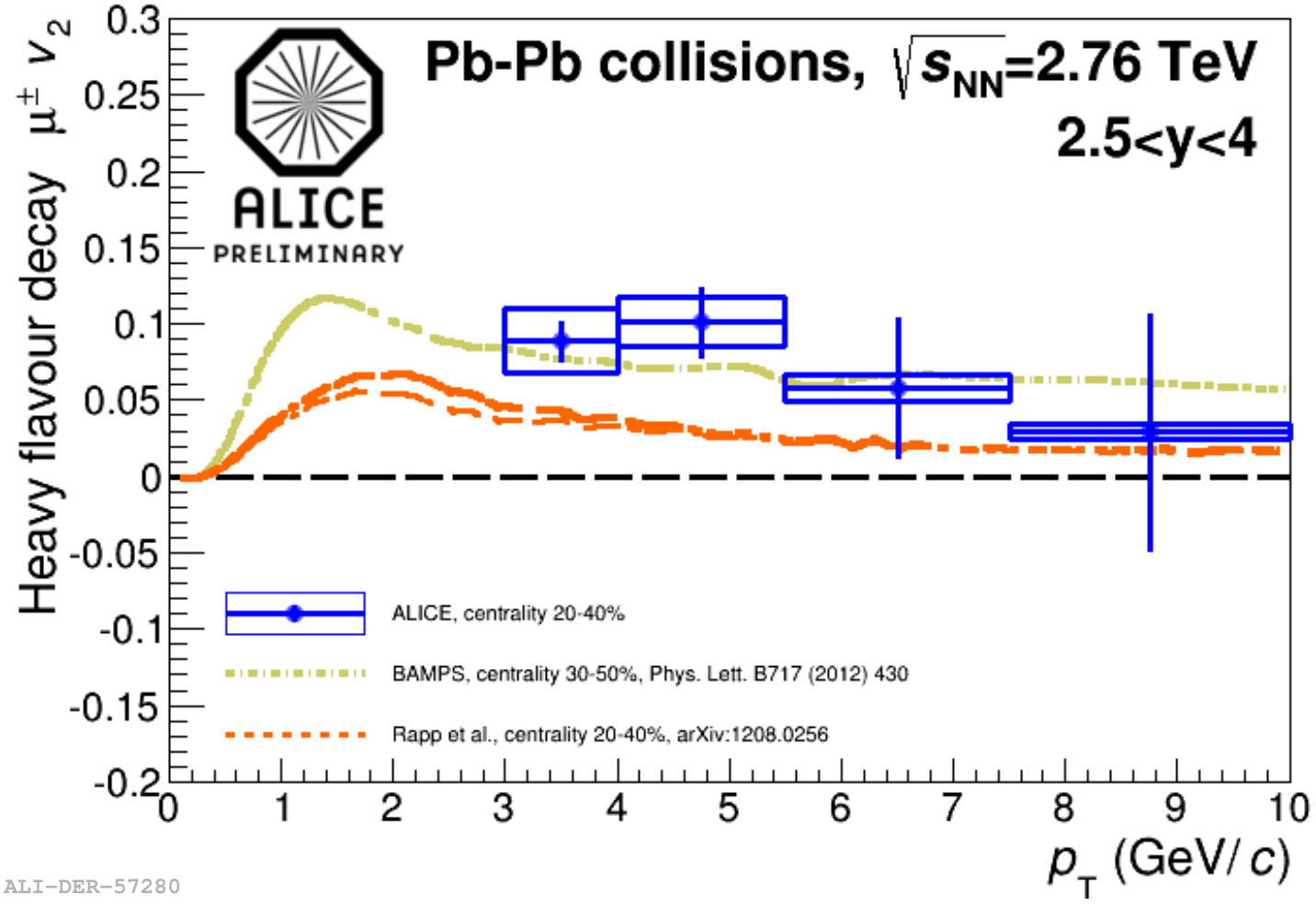
D. Thomas Thu 15:00

Simultaneous description of heavy flavor decay electrons R_{AA} and v_2 is a challenge to theoretical models

Flow of heavy-flavor muons

X. Zhang Tue 16:20

NEW

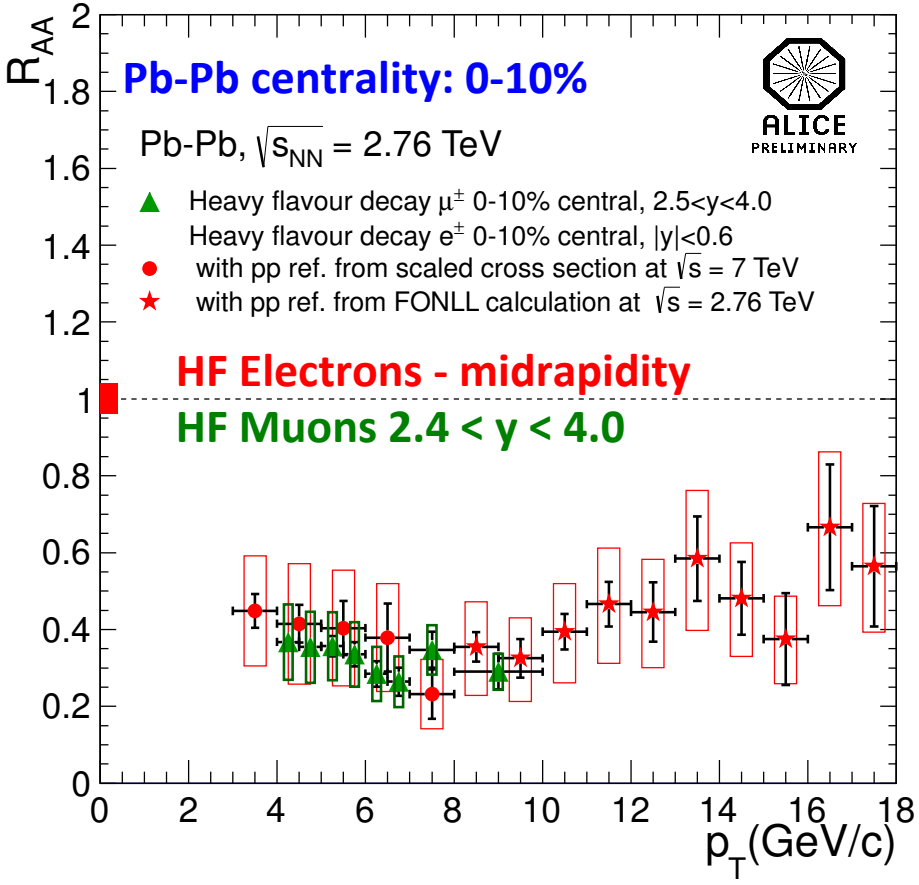


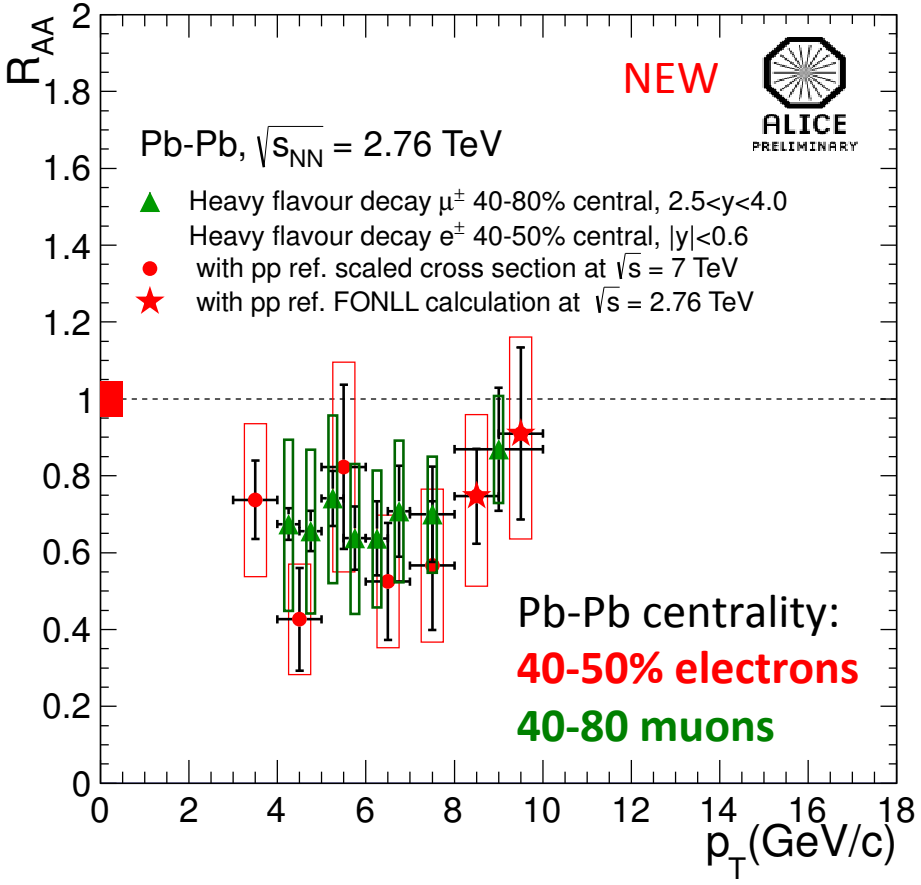
20-40%: v_2 of HFM similar as for HF-electrons in central rapidity

Heavy-flavor electrons

D. Thomas Thu 15:00

- Pb-Pb: Heavy-flavor electrons at **|η|<0.7** and heavy-flavor muons at **2.4<|η|<5**
  - **Similar suppression pattern (centrality dependence) for muons and electrons**



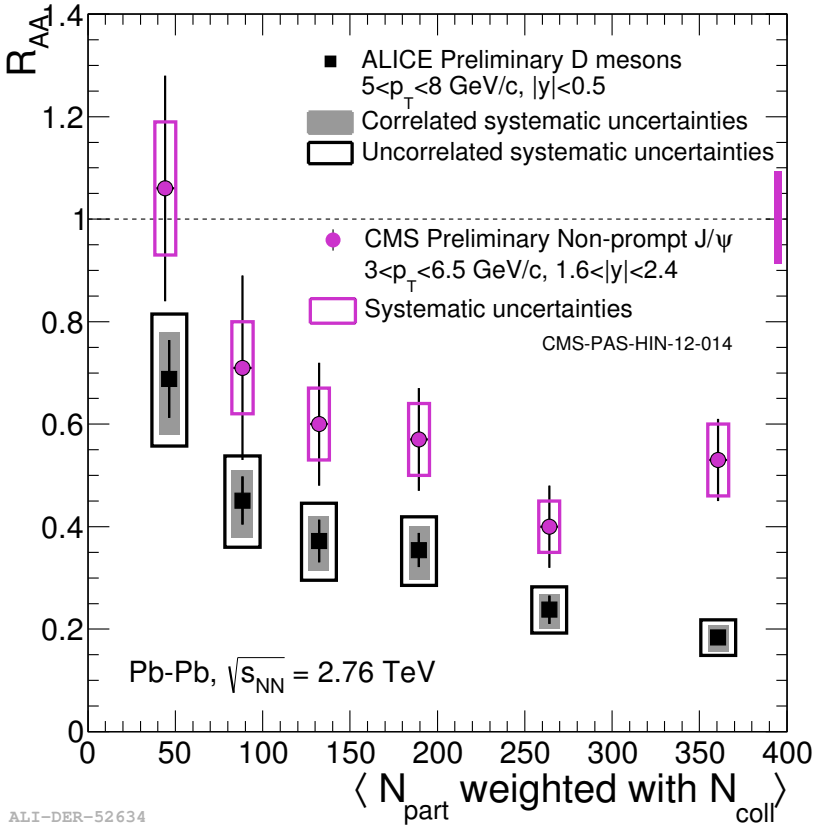


ALI-DER-36791 ALI-DER-53851

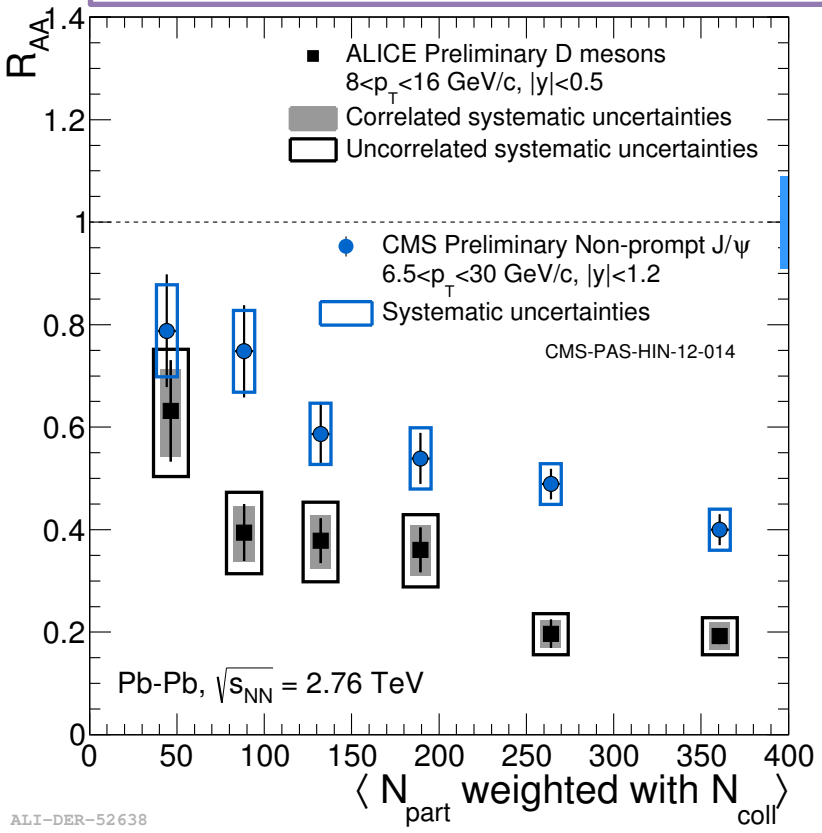
D vs. B mesons RAA vs. centrality

E. Bruna Thu 15:20

D's 5-8 GeV/c – NP J/ψ 3-6.5 GeV/c



D's 8-16 GeV/c – NP J/ψ 6.5-30 GeV/c



- pT ranges: similar kinematics for D and B mesons (measured via non-prompt J/ψ)
  - simulations of decay kinematics used, i.e. in 8-16 GeV/c, in J/ψ pT range 6.5-30 GeV/c

Charm more suppressed than beauty

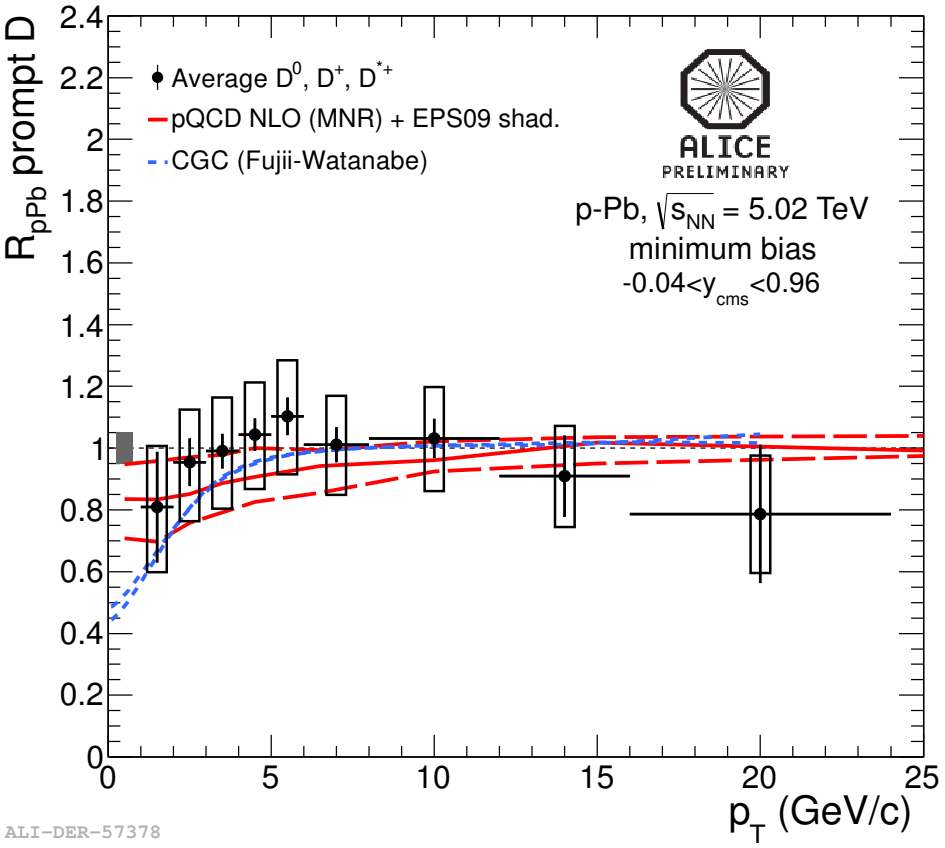
TW

Heavy-flavor in p-Pb

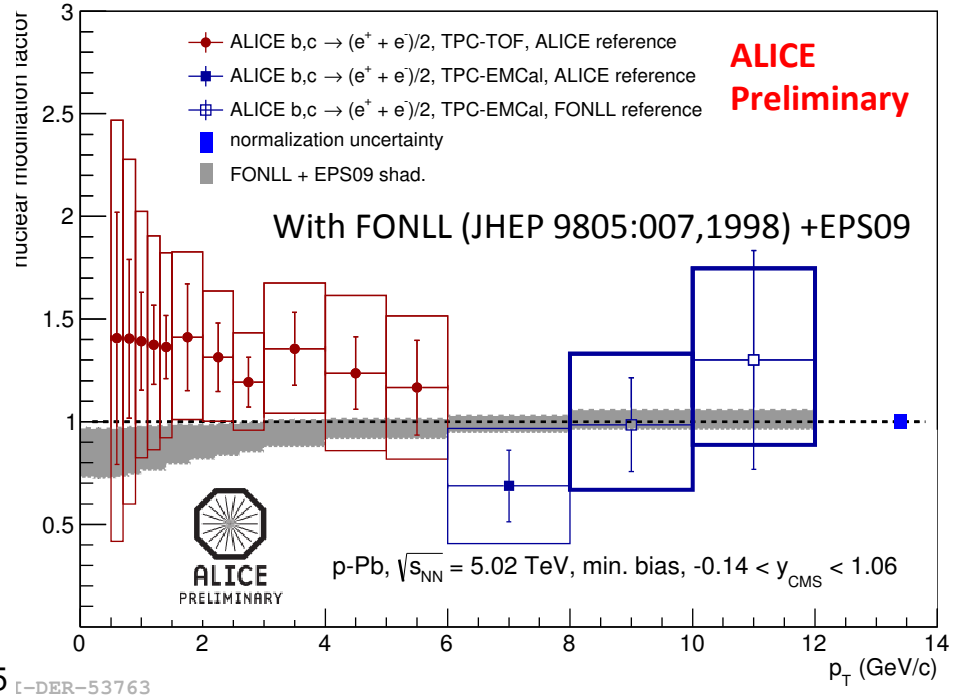
D. Stocco Tue 11:00
G. Luparello Fri 14:00
M. Heide Fri 14:20

D-meson R_{pPb} consistent with MNR + EPS09 and CGC calculations

MNR: Nucl. Phys. B 373 (1992) 295; EPS09: JHEP 0904 (2009) 065



Heavy-flavor electrons in p-Pb

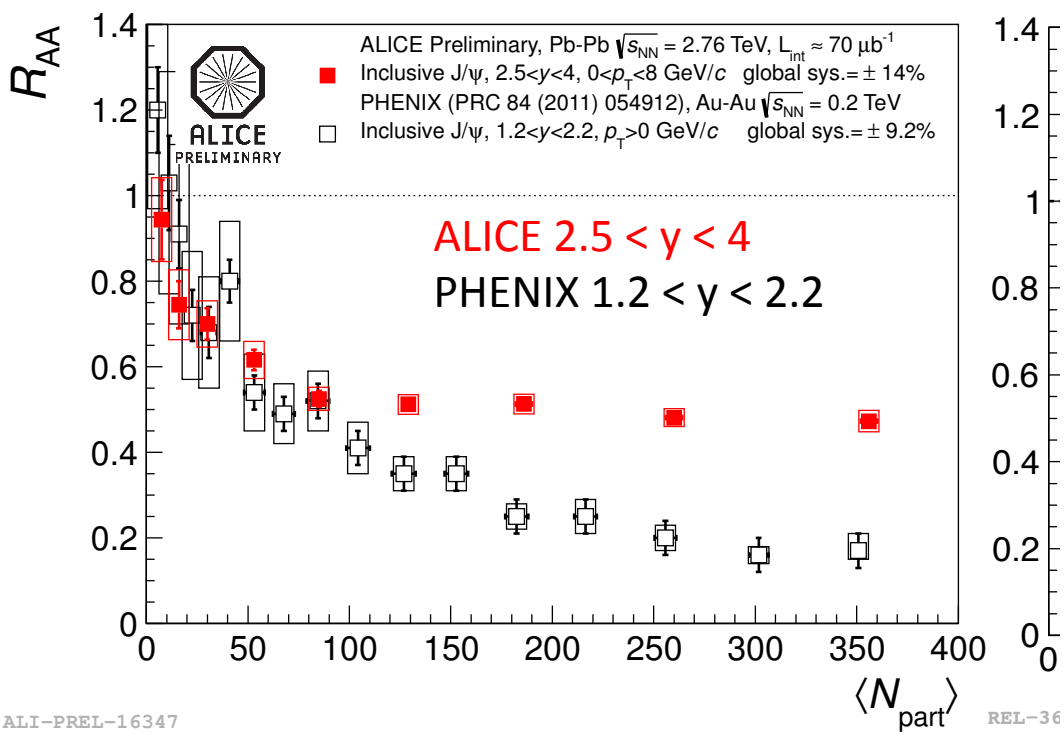


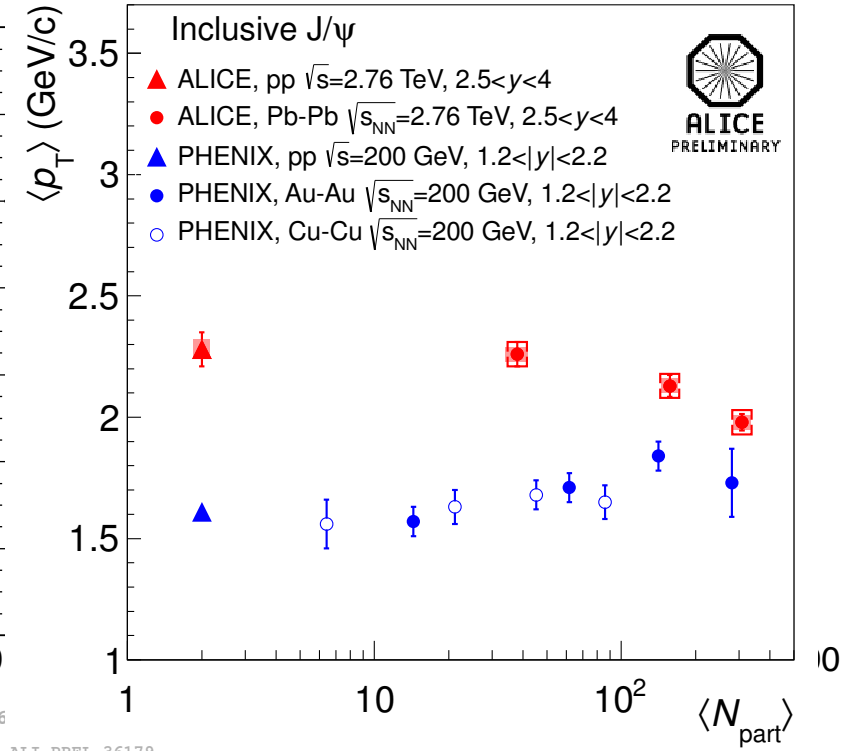
HF at mid-rapidity R_{pPb} consistent with unity (within uncertainties)

QUARKONIA

J/psi in Pb-Pb

- Different suppression pattern as compared to RHIC – much less suppression in central events -> recombination?
- Stronger suppression at larger rapidities (consistent with electron results) – challenge to the model (E. Ferreiro, shadowing+comovers+recomb.)



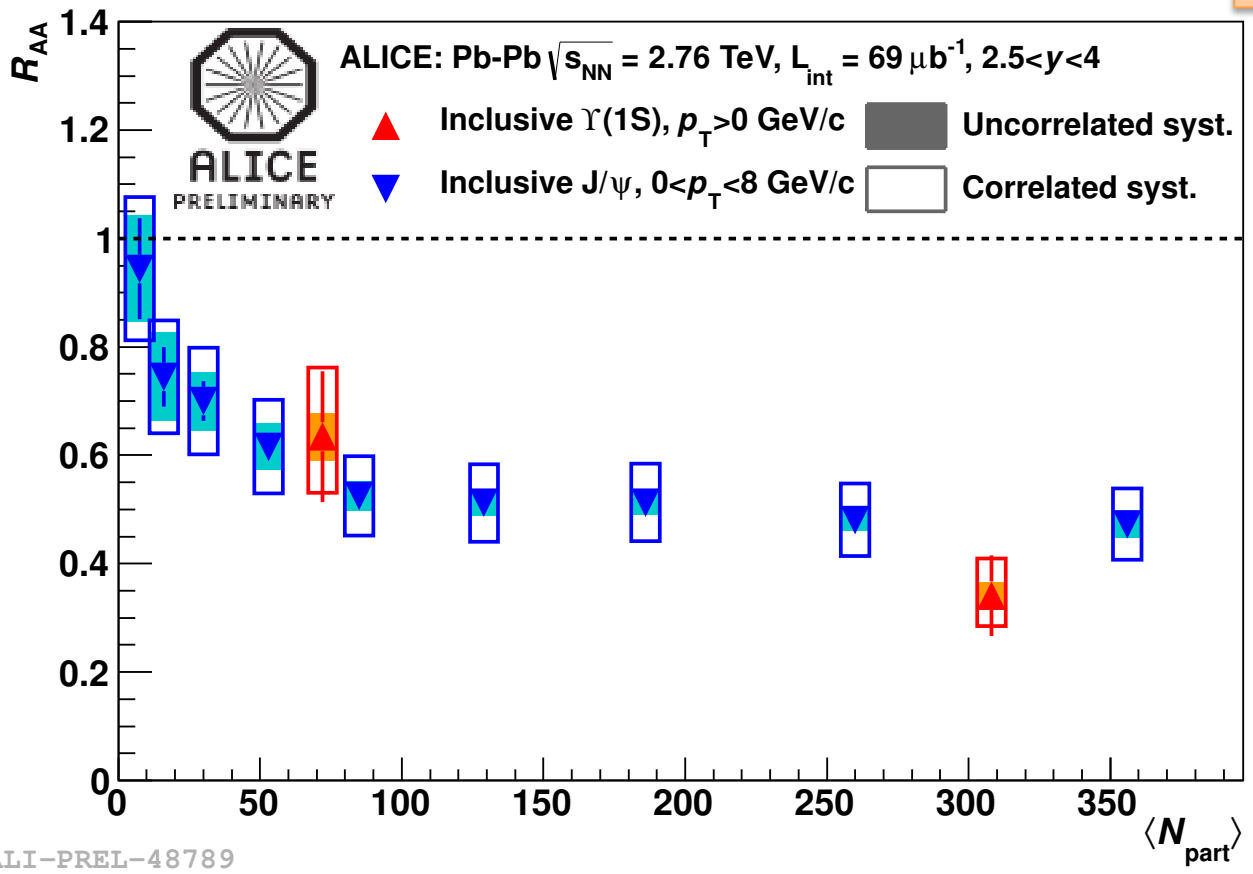


G. Bruno Tue 09:00
L. Valencia Palomo Fri 16:50

< p_T > evolution with <N_{part}>: different than at RHIC ?

Upsilon in Pb-Pb

G. Bruno Tue 09:00
P. Khan Fri 17:10

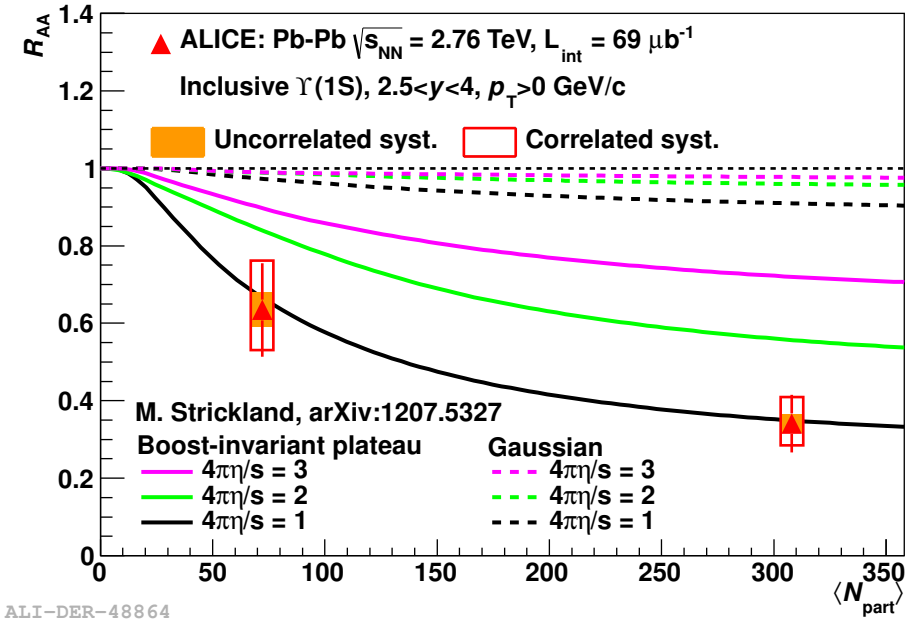


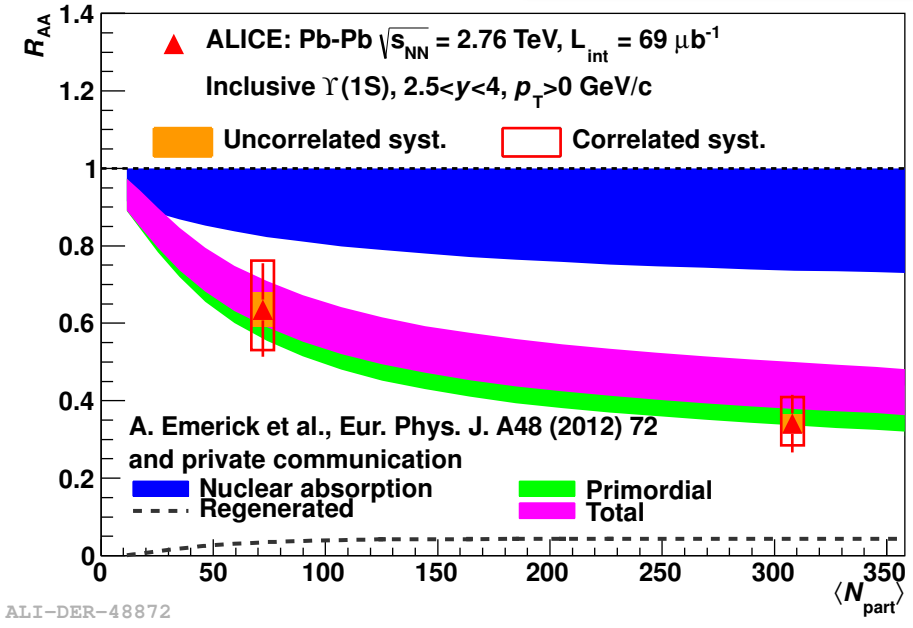
Similar suppression for Y and J/psi within uncertainties

Note: less regeneration for Y; feed down from Y(2S), Y(3S), χ_b, χ'_b is ~50%

Upsilon in Pb-Pb

G. Bruno Tue 09:00
P. Khan Fri 17:10



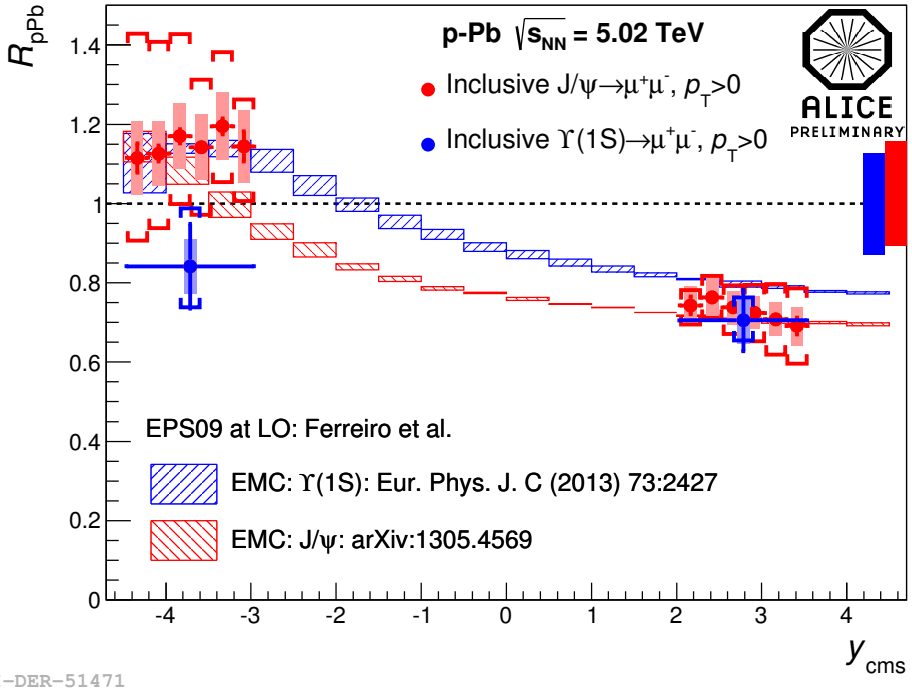


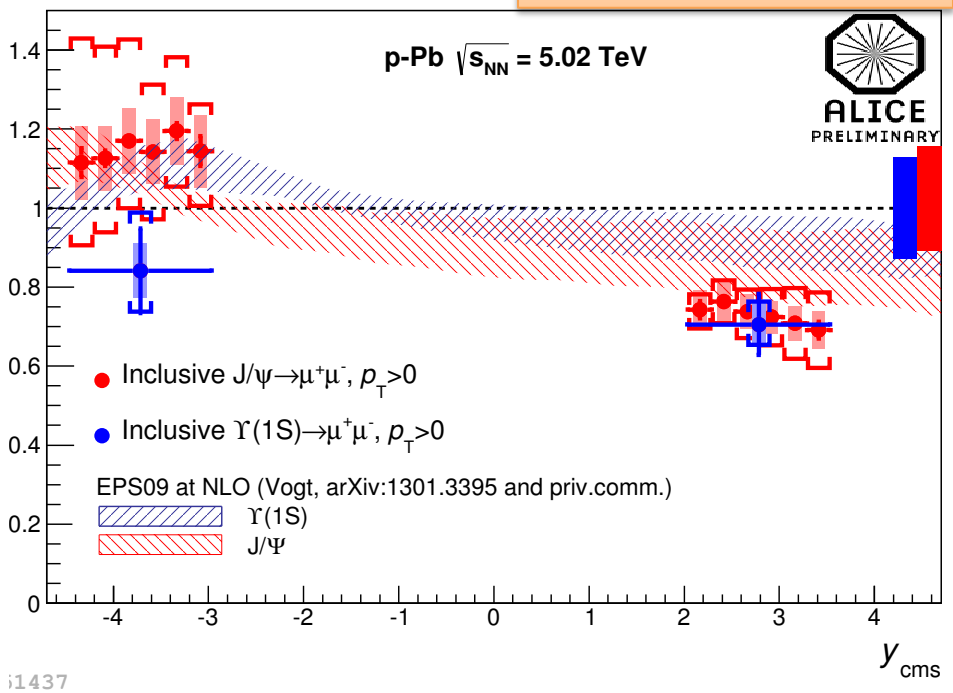
- M. Strickland: Hydrodyn. model w/ feed down of Y(1S) from higher states; no recombination; no CNM;
- Data agree with the boost invariant plateau with limited fragmentation for η/s of 1/4π

- Emerick et al.: rate equation w/ small regeneration, feed-down (~ 50 %) and CNM effect by an overall absorption cross-section
- Agreement with the data within uncertainties

Quarkonia in p-Pb

G. Bruno Tue 09:00
I. Lakomov Fri 15:00





EPS09 + LO by Feirreiro (color singlet) - describes the data within uncertainties - better for J/psi

EPS09 + NLO from Vogt (color octet) describes the J/ψ data; reproduces, with slightly larger values, the observed trend for Y(1S)

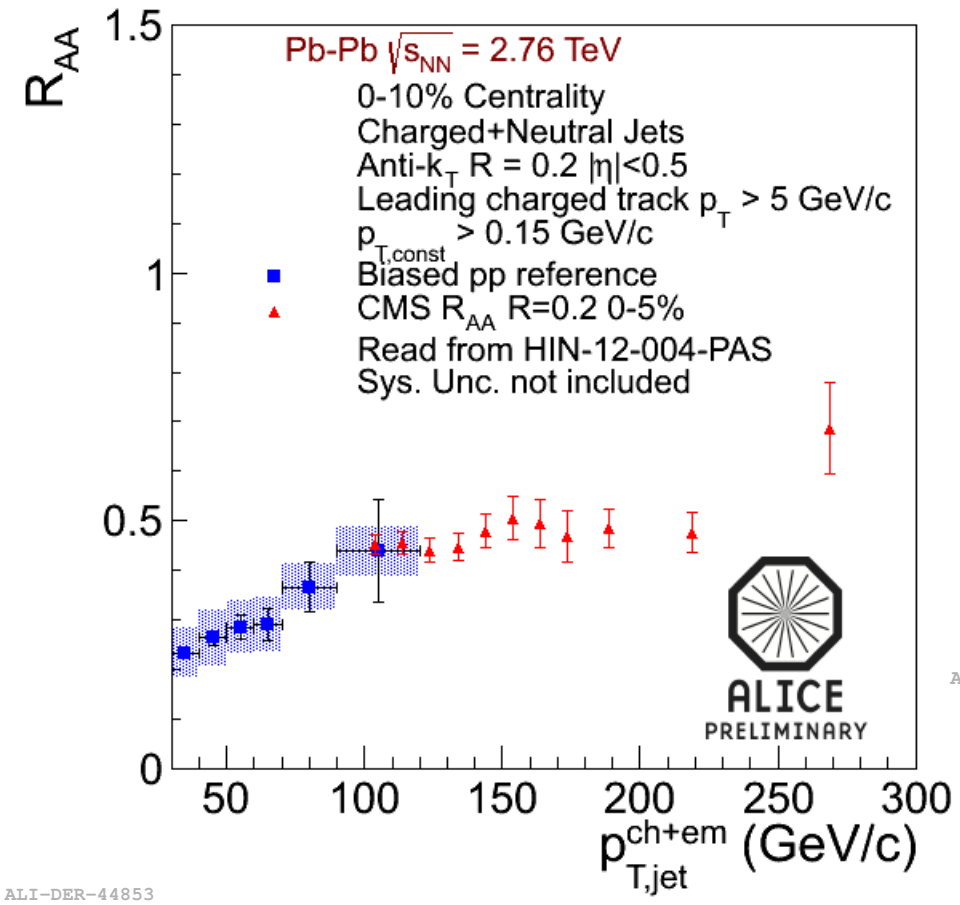
Number of models reproduce the FB ratio within experimental uncertainties; low shadowing favor Y(1S), high shadowing better with J/ψ data

JETS

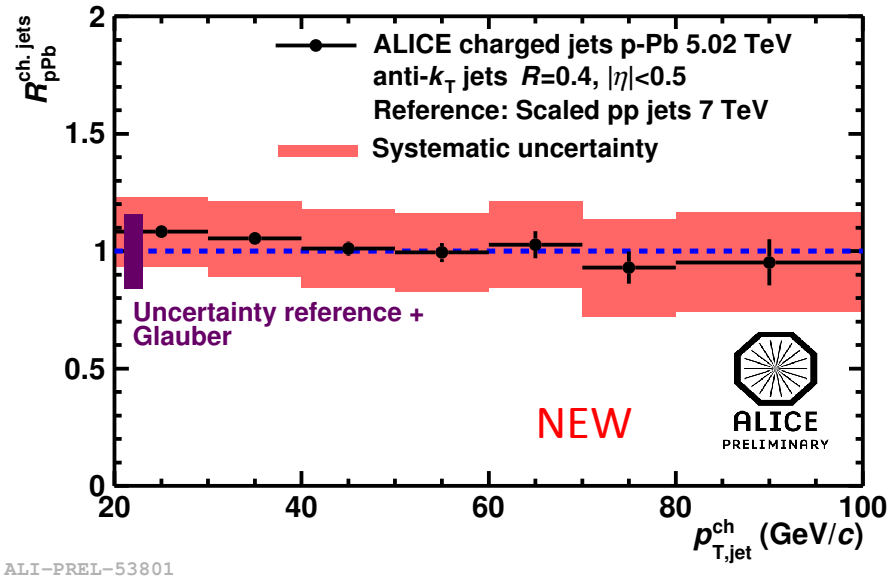
Jet R_{AA} and RpPb

M. Verweij Thu 14:20

Jets strongly suppressed in central Pb-Pb



No suppression in min. bias p-Pb collisions



Jet x-section ratios (R=0.2/R=0.4) in Pb-Pb and pPb compatible with pp within uncertainties (not shown here) – no modifications of internal jet structure within uncertainties

And many other…

- Ultra-peripheral collisions Friday 26 Jul 2013
- D meson-hadron correlations in pp and p-Pb
- Flow of strange and multi-strange particles
- Charmonium in Pb-Pb Friday 26 Jul 2013 at
- D RAA and v2 in Pb-Pb Thursday 25 Jul 2013
- Hadronic resonances in Pb-Pb Thursday 25 J
- J/psi production in p-Pb Friday 26 Jul 2013 a
- Jet production and structure in pp, p-Pb and
- K0s and Lambda Thursday 25 Jul 2013 at 17:
- Low mass vector meson production in pp, p-
- D meson production in p-Pb collisions Friday 26 Jul 2013 at 14:00 by G. Luparello
- Electrons from heavy-flavour decays in Pb-Pb Thursday 25 Jul 2013 at 15:00 by D. Thomas
- Electrons from heavy-flavour hadron decays in pp and p-Pb Friday 26 Jul 2013 at 14:20 by M. Heide
- J/psi->ee with ALICE Friday 26 Jul 2013 at 16:30 by F. Fionda
- Multi-strange baryon production in Pb-Pb and pp collisions Thursday 25 Jul 2013 at 16:50 by D. Colella
- RAA and v2 of muons from Heavy-Flavour in Pb–Pb Tuesday 23 Jul 2013 at 16:20 by X. Zhang
- Open-charm production vs. charged-particle multiplicity in pp Thursday 25 Jul 2013 at 15:40 by R. Bala
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- Tracker upgrade Thursday 25 Jul 2013 at 16:30 by C. Terrevoli
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- Search for exotic hyper-matter and measurement of (anti-)nuclei yields Friday 26 Jul 2013 at 17:30 by B. Doenigus
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- Upsilon Production in Pb-Pb Collisions at Forward Rapidity Friday 26 Jul 2013 at 17:10 by P. Khan

Plenary talks:

Strangeness Monday 22 Jul 2013 at 15:50 by L. Barnby
Quarkonia Tuesday 23 Jul 2013 at 09:00 by G. Bruno
HF Tuesday 23 Jul 2013 at 11:00 by D. Stocco
pA collisions Thursday 25 Jul 2013 at 11:30 by A. Morsch
Angular correlations Friday 26 Jul 2013 at 10:00 by P. Christakoglou

In red talks not mentioned earlier

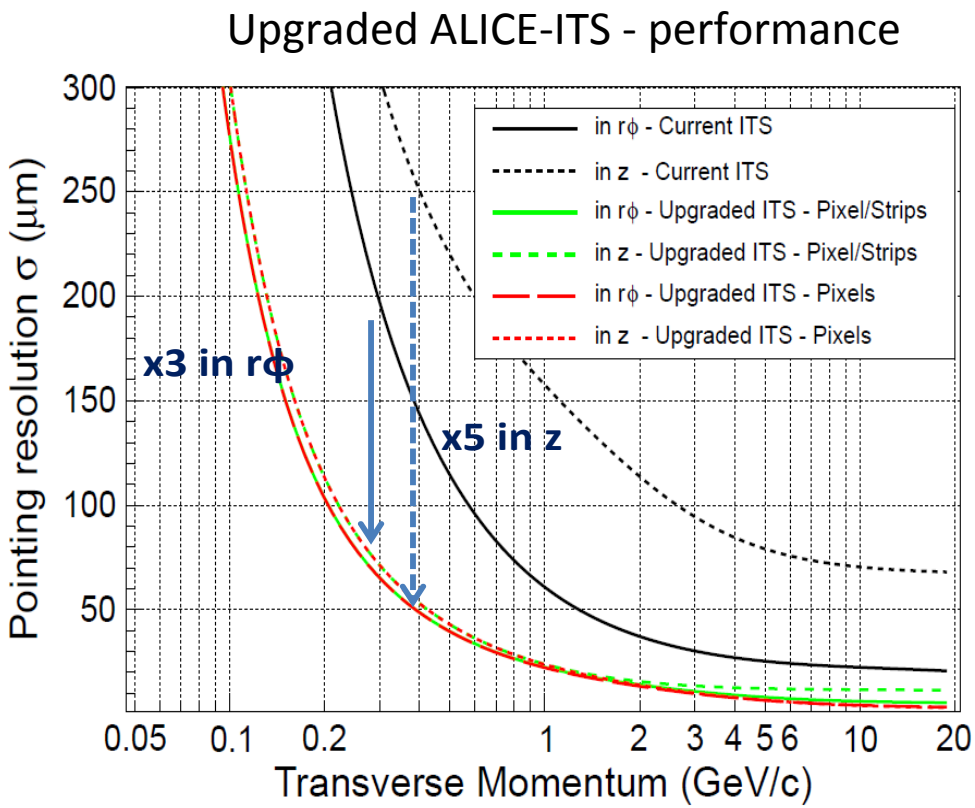
Summary

- More details on particle production in Pb-Pb
  - Resonances, multi-strange particles… - including flow…; including quarkonia
  - Critical for in-depth understanding of QGP properties
- R_{pPb} delivers wealth of cross-checks / new calibration measurements
  - R_{pPb} is 1. for jets, open charm, heavy-flavor (min. bias)
  - CNM effects are finite in quarkonia production
  - Understanding of "centrality" in pA collisions not trivial
  - Observables used to probe genuine QGP/hot coupled system properties reveal similar features in "cold" collisions (pA and(!) proton-proton collisions)

ALICE Inner tracker upgrade

C. Terrevoli Thu 16:30

- Readout: continuous readout of Pb-Pb interactions at > 50 kHz
  - to exploit luminosity (>10 nb-1 in Pb-Pb - ~10^{10} central events)
- New ITS:
  - Exploit heavy-flavor physics with precision and stat. accuracy
  - Tracking efficiency >90% down to 0.1- 0.2 GeV/c
  - Stand-alone pT resolution: improved by a factor ~2



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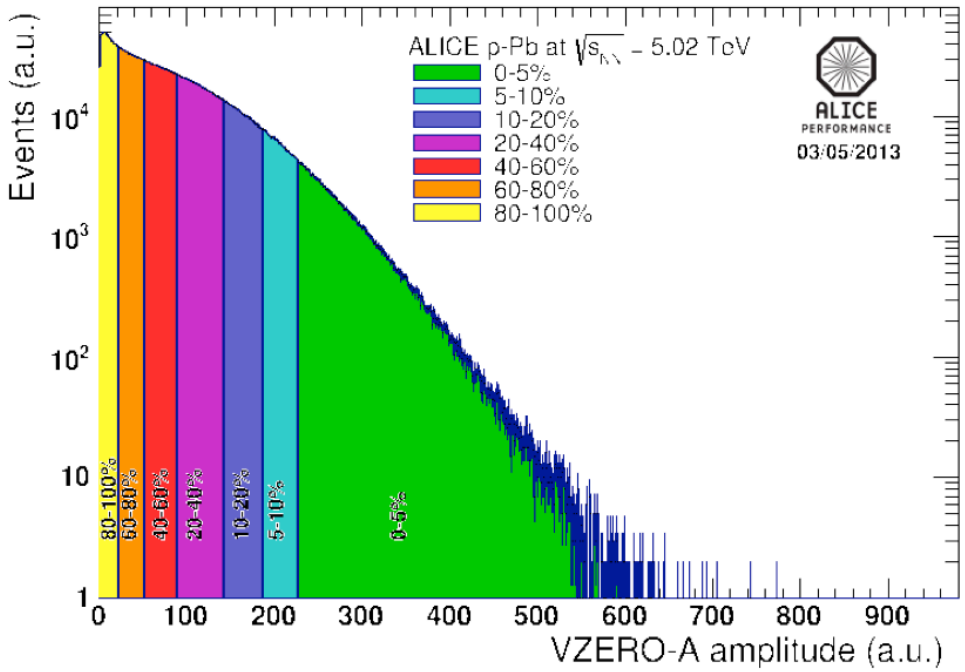
In red talks not mentioned earlier

EXTRA SLIDES…

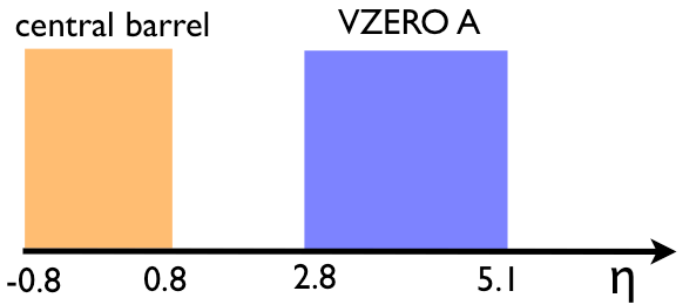
Longer summary – wealth of information…

- Particle production in Pb-Pb: tension between protons and Λ, Ξ, Ω; p-pbar annihilation?; missing resonances?; non-equilibrium effects?;
- Known resonances: signature of re-scattering in hadronic phases of central collisions; ϕ/K agrees with GC thermal model; R_{AA} ϕ : a baryon below 2 GeV and meson above; Ξ compatible with protons; Ω suppressed in pp – R_{AA} large value
- Identified particle v_2 – n_q scaling approximate at LHC (at best) – heavier particles follow hydrodynamic predictions
- R_{pPb} minimum bias is ~ 1 within uncertainties for jets, D's, HFE; below 1. for forward quarkonia (Pb CNM; shadowing; finite e-loss)
- Effects ascribed to collective phenomena in Pb-Pb also present in p-Pb? – v_2 of identified hadrons – need to test the observables – what are the genuine QGP signatures? – collectivity in pp via color reconnections (pythia) – also must be present in p-Pb…; centrality-Glauber Ncoll scaling in pA not simple (physics biases in multiplicity measures)
- Similar trend (power law) behavior of particle ratio (baryon/meson) in pp, p-Pb, Pb-Pb as a function of transverse momentum
- Open charm strongly suppressed flows in Pb-Pb (similar observations for heavy-flavor electron and muon v_2) – signature of charm interactions within the medium
- Quarkonia: in p-Pb the forward-backward ratio for Y found smaller than for J/ψ; CNM is not zero; R_{AA} J/ψ larger than at RHIC - regeneration in central Pb-Pb?
- Jets suppressed in PbPb but their structure as in vacuum within uncertainties – consistent with identified particle RAA – common suppression for pi, K, p



track reconstruction

event multiplicity determination



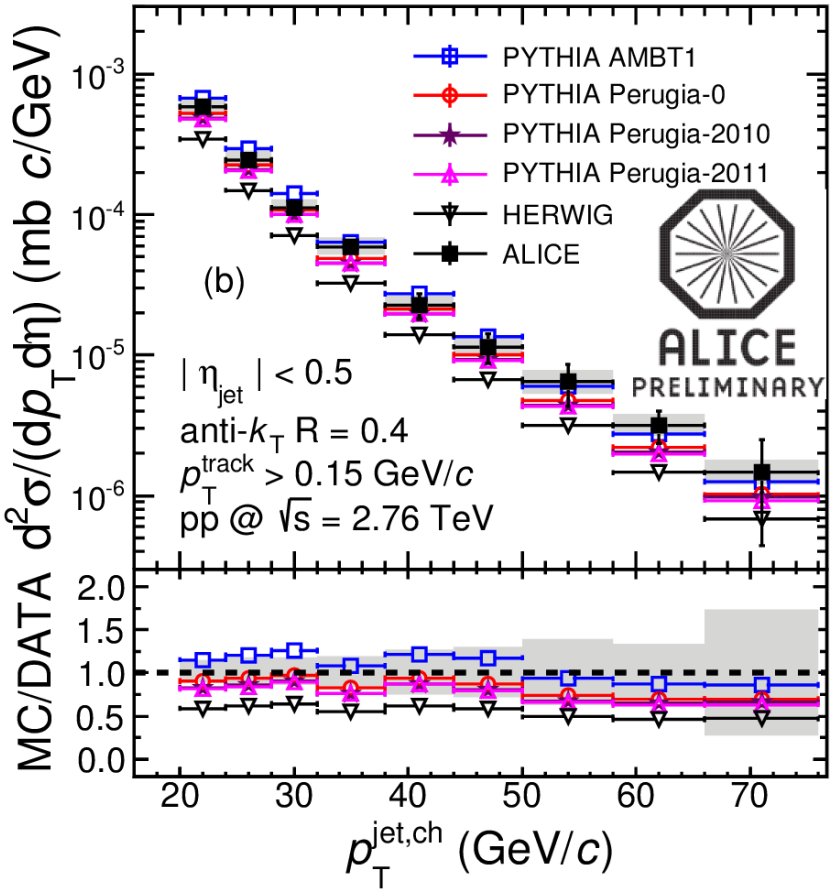
Jets in ALICE

Marta Verweij

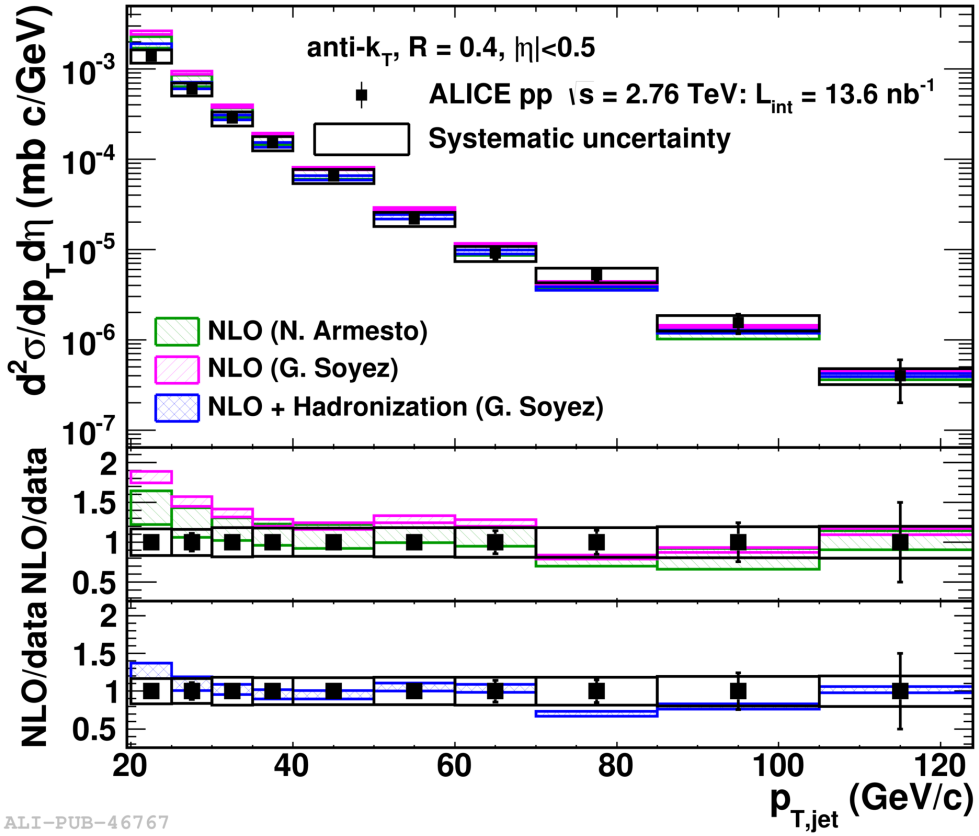
Measured with charged tracks (ITS+TPC) and nautral particles (excpt n and K0L; with EMCal)
Background corrections: event-by-event average bg. subtracted + unfolding of spectra

Proton-proton

Charged Jets



Full Jets



ALI-PUB-46767

Phys Lett B 722 262-272 (2013)

Jets in ALICE

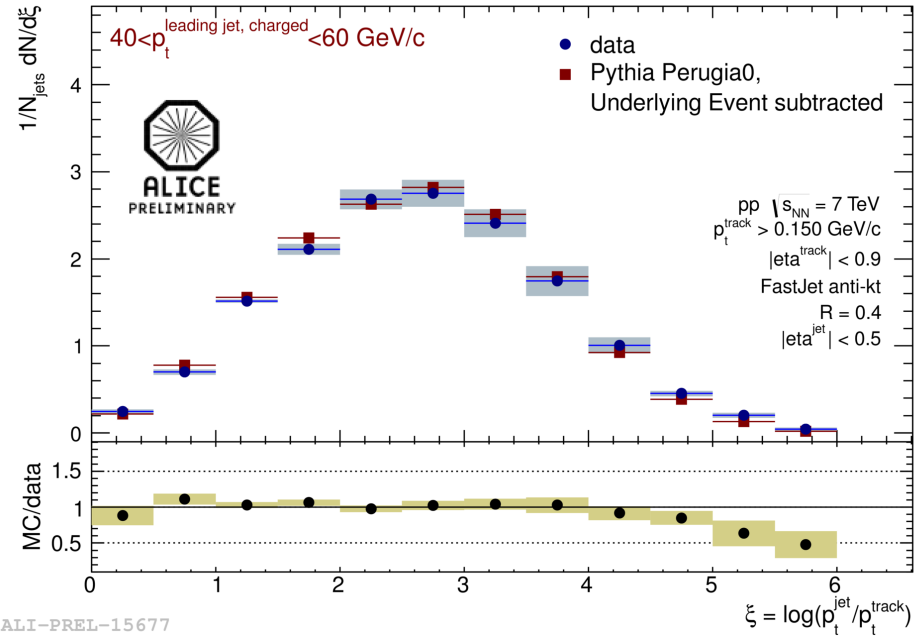
Marta Verweij

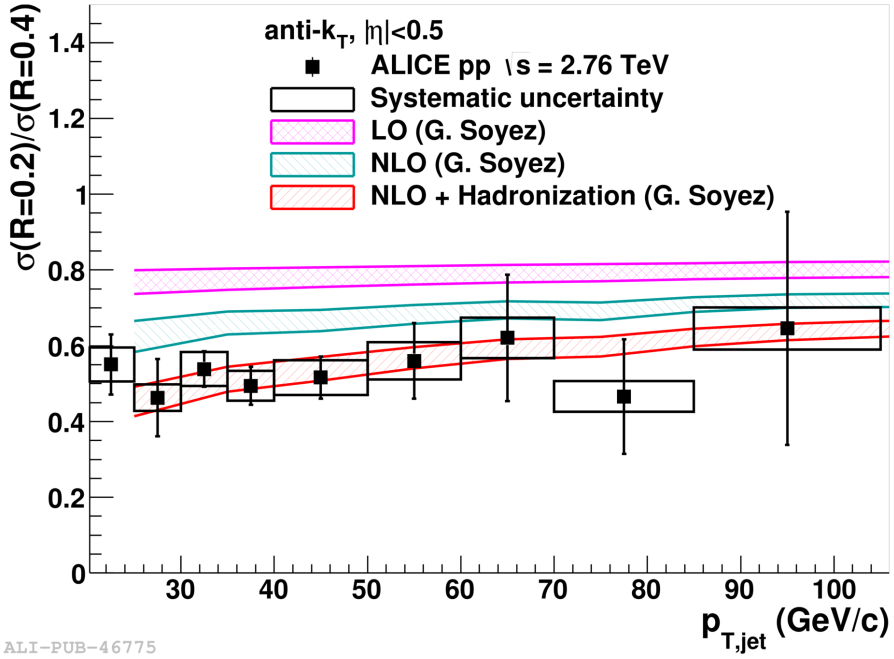
Measured with charged tracks (ITS+TPC) and nautral particles (excpt n and K0L; with EMCal)
Background corrections: event-by-event average bg. subtracted + unfolding of spectra

Momentum distribution of jet constituents

Proton-proton

Cross section ratio $\sigma(R=0.2)/\sigma(R=0.4)$





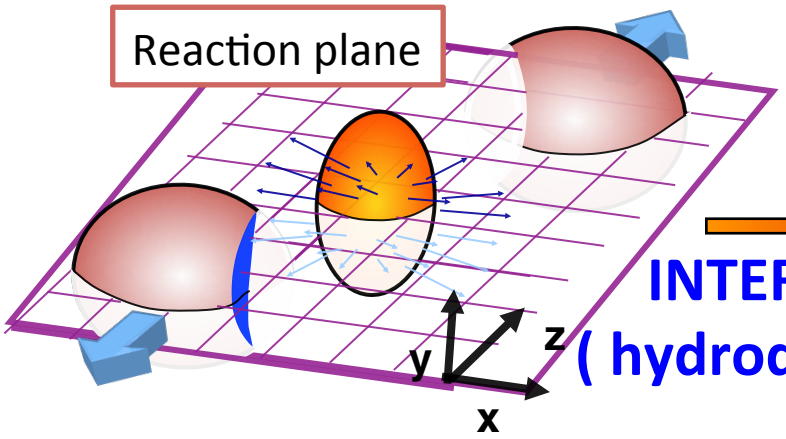
Phys Lett B 722 262-272 (2013)

Scaled momentum $\xi = ln\,(p_{\mathrm{T}}^{\mathrm{jet,ch}}/p_{\mathrm{T}}^{\mathrm{particle}})$

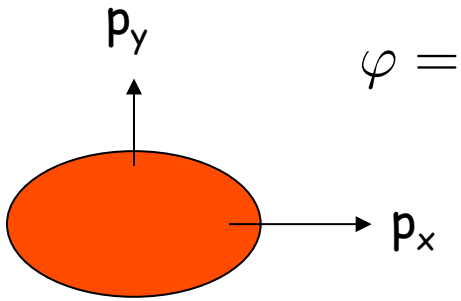
→ hump-backed plateau

Jet transverse structure.
Consistent with rising trend:
jet collimation.

Collective Flow of QCD Matter



INTERATIONS
(hydrodynamics?)



$$\varphi = \arctan \frac{p_y}{px}$$

$$\varepsilon = \frac{\langle y^2 \rangle - \langle x^2 \rangle}{\langle y^2 \rangle + \langle x^2 \rangle}$$

Initial spatial anisotropy

$$v_2 = \frac{\langle p_x^2 \rangle - \langle p_y^2 \rangle}{\langle p_x^2 \rangle + \langle p_y^2 \rangle}$$

Final momentum anisotropy

Reaction plane defined by "soft" (low p_T) particles

$$\Delta\varphi = \varphi - \varphi^{Reaction\ Plane}$$

Elliptic flow

$$\frac{dN}{d\Delta\varphi} \propto 1 + 2v_2 \cos(2\Delta\varphi)$$